TECHNOLOGY ASSESSMENT AND TECHNOLOGY TRANSFER OF "3D PRINTING TECHNOLOGY" IN BANGLADESH

by

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CERTIFICATE OF APPROVAL

The thesis titled "**Technology Assessment and Technology Transfer of "3d Printing Technology" in Bangladesh**" submitted by Md. Ashrafuzzaman, Student ID: 0413292082, Session: April 2013 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Management of Technology on 05 September, 2020.

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I am grateful to the Almighty Allah for the good health and wellbeing that were necessary to complete this research.

I would first like to thank my thesis supervisor Dr. Mohammad Arif Hasan Mamun, Professor and Director of Institute of Appropriate Technology (IAT) at Bangladesh University of Engineering and Technology (BUET). He consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

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Finally, I must express my very profound gratitude to my parents, sisters and brother for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

ABSTRACT

The additive manufacturing process or 3D printing technology has the potential to speed up the innovation and product creation processes to step towards digital fabrication. The 3D printing process is helping the consumers to free themselves from traditional suppliers and acquire & design their own products according to their own design and requirements. The Fused Deposition Modelling (FDM) is the most matured and cost efficient technology worldwide which patent already expired for the open source community.

In this research work, the 3D printing technology are assessed for Bangladesh. Multi-Criteria Decision Making (MCDM) analysis has been deployed to evaluate different criteria and reach the most appropriate decision. Organizing the complex problems efficiently and taking into account multiple criteria leads to more informed and better judgments and choices. AHP is one of the most accurate technique for computing the relative weights of multiple criteria. The experiences from individual experts are utilized to approximate the relative magnitude of different factors using pair-wise comparisons. Each of the expert has to compare the relative importance of the two different items using a questionnaire specially designed for this purpose. A questionnaire was built specifically for this purpose and handed over to 10 3D printing technology experts. They evaluated the technologies and weighted them according to best of their expertise and experienced knowledge. Many criteria like cost, raw material availability, maintenance and production rate etc. Final weights were calculated and final results were designed using the weighted moving average giving priority to the more relevant data. It was concluded that the FDM technology was most appropriate for deployment in current manufacturing status of Bangladesh.

From this thesis the financial feasibility study identified the most appropriate technology industrial sector to deploy the different types of polymer based 3DP technology. Also, through triple helix method mentioned specific area of contribution and responsibility of Academia, Government & Industry to implement this new technology to upgrade the traditional manufacturing sector into Digital Manufacturing system for Bangladesh.

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LIST OF ABBREVIATIONS

- AM- Additive Manufacturing
- 3DP- 3D Printing
- SLA- Stereo-lithography
- MJ- Material Jetting
- DLP SLA -Digital Light Processing Stereo-lithography
- LCD SLA Liquid Cristal Display Stereo-lithography
- SLS-Selective Laser Sintering
- SLM- Selective Laser Melting
- EBM- Electron Beam Melting
- LOM -Laminated Object Manufacturing
- PJ- Photopolymer Jetting
- FDM -Fused Deposition Modeling
- CLIP -Continuous Liquid Interface Production
- AHP- Analytic Hierarchy Process
- CI Consistency Index
- CR Consistency Ratio
- MCDM -Multi Criteria Decision Making
- CAD- Computer-Aided Design
- CNC- Computer Numerical Control
- FabLab- Fabrication Laboratory
- RM- Raw Material
- BAT-Binder Adhesive Type
- ROI- Return on Investment
- IRR- Internal Rate of Return
- TH- Triple Helix
- TT- Technology Transfer

CHAPTER 1: INTRODUCTION

1.1 Background of the Thesis

The 3D printing technology builds a three-dimensional object from a 3D computer-aided design (CAD) model by successively adding material layer by layer which is also called additive manufacturing. 3D printing or AM (Additive Manufacturing) is become a tremendous and potential game-changing method of manufacturing which has the capability to change all of the existing traditional manufacturing process. The traditional manufacturing tools like saws, lathes or drills start from a bulk of raw material and keep trimming the bulk until the desired shape is achieved. A 3D printer adds raw materials in 2D and keeps adding design layers until the desired products are achieved. The 3D printer does not need a costly mold. Also it enables the formation of intricate, complex, hollow interlocking parts in one production cycle. Through this technology you can make almost anything you want whereas a popular comment "If You Can Draw It, You Can Make It" [1]; It has demonstrated an ability to expedite the speed of innovations and create products that were previously not possible [2]. 3D printing is shifting the production of objects from the factory to the home. It enables consumers to free themselves from traditional suppliers and gives them the choice to follow their own acquisition strategy [3]. Almost any object can be created with a 3D printer such as motor vehicles, aerospace, machinery, electronics, medical products, clothing, toys, weapons, prosthetic body parts, jewelry, houses, shoes, eye wears etc. [4, 5]. The terms 3DP and AM are often used interchangeably, as both refer to the layer-by-layer creation of physical objects based on digital files that represent their design." and "The term additive manufacturing has come to represent the use of 3DP to create final parts and metallic components, differentiating from the more traditional subtractive manufacturing processes." Where traditional fabrication tools - such as lathes, saws, drills and rototillers - take a chunk of raw material and trim it down to form a shape (subtractive manufacturing), a 3D printer does the opposite. As the technical term suggests, 3D printers add raw material one tiny layer at a time eventually fabricating an entire object. Unlike plastic injection molding, a 3D printer does not require a costly mold, only a digital design file containing the information of the desired object. Consequently, 3D printing is the first manufacturing method that allows the production of intricate designs with hollows and interlocking parts [6, 7].

It is predicting that next industrial revolution will come through 3D printing technology. But Bangladesh is still far behind in the race of manufacturing process technological change through 3D Printing. Despite of some large hi-tech company still most of the company unable to adopt this technology in their regular production process. So far this technology in Bangladesh at R&D stage, but it is matter of good prospect that most of the public universities, polytechnic institutes are opening their 3D printing lab as well as FabLab (Fabrication Laboratory). Some new entrepreneurs developing company based on this additive manufacturing technology. Depends on mechanism, process and material 3D printing technology can be divided into more than 30 categories. Among many kinds different technology it is very important to select the most appropriate technology based on its application. In this circumstances, I am motivated to do the thesis on selection of most appropriate 3D printing technology in the perspective of Bangladesh; study based on available polymer based technology. Without the appropriate choice of this technology selection it will not economically viable. To select the appropriate technology Multiple-criteria decision-making (MCDM) based AHP technique is the best way of selection which has been used in this study. Also in this study mentioned different sector wise case study on financial feasibility of 3D printing technology in different sectors of Bangladesh compared to existing traditional manufacturing process. Also studied the possible area of integration for 3D printing in traditional manufacturing process. After that provided recommendation to adopt this technology in Bangladesh based on Triple Helix model of University, Academia (Educational Institutions) and Industry/Business sector interactions. Because without the proper collaboration among Government, Academia and Industry; it is not possible to adopt this new technology easily. To be competitive in global manufacturing market for Bangladesh, it is very important to implement the appropriate 3D technology immediately to meet customer demand in efficient and responsive way.

1.2 Objectives of the Research

Consolidating the concerns discussed in the previous section, the objectives of the research are-

I. To assess the 3D Printing Technology in Bangladesh through Multi-Criteria Decision Making (MCDM) analysis.
II. To implement Triple Helix Framework for Technology Transfer of 3D printing technology in Bangladesh.
III. To evaluate financial benefit of 3D printing technology in different industrial sectors of Bangladesh.

1.3 Significance of the Research

- AHP method will be very useful before selecting any kind of 3D printer and identified criteria to find the solution of different types of manufacturing problem.
- Also through this research method possible to basic comparison between traditional manufacturing and additive manufacturing to solve individual manufacturing problem.
- Possible to identify major contribution area for Government. Academia & Industry to implement the 3D printing technology in Bangladesh.

All of this significance is very important for implementation of additive manufacturing technology in Bangladesh.

CHAPTER 2: LITERATURE REVIEW

2.1 Subtractive Manufacturing vs. Additive Manufacturing

In broader sense manufacturing process can be divided into two categories; Additive & Subtractive manufacturing. Additive manufacturing is a process that adds layer by layer of material to create an object, often referred to as 3D printing. This additive manufacturing is the synonym of 3D printing.

On the other hand, Subtractive manufacturing is the opposite principal of additive manufacturing. Rather than adding layers, subtractive manufacturing involves removing of a material by machining or cutting it away. It can be carried out manually or automatically, more commonly, by a process known as Computer Numerical Control (CNC) machining.
The 3D printing process is a recent technology for product manufacturing. It uses a computer-aided design (CAD) model to build a three-dimensional object by adding layer by layer material [4]. This is in contrast to the conventional product manufacturing processes where the product is built using subtractive techniques or moulds [5,6].

2.2 Major Categories in 3D Printing

Many processes and materials are used in 3D printing. The 3D printing processes have many similarities like the system input is a 3D model and the construction builds by assembling the material in layers. It is beneficial to divide the wide range 3D printing processes into different process categories. Following are different Major categories based on mechanism as approved by ASTM: [7, 63]

- Material Extrusion: in this 3D printing process the material is selectively distributed using an orifice or nozzle.
- Material jetting: in this 3D printing process the building material droplets are deposited selectively.
- Binder jetting: in this 3D printing process a liquid binding agent is used, and is deposited as a binder to join powder materials.
- Vat Photo polymerization: in this 3D printing process a liquid photopolymer in a vat uses light-activated polymerization for curing.

- Sheet lamination: in this 3D printing process object is made by bonding the sheets of different materials.
- Powder bed fusion: in this 3D printing process regions of power bed a fused selectively using thermal energy.

2.3 Material used in 3D Printing

The 3D printing materials majorly lie in two categories that are plastics and metals. However, there are other filled and composite materials available. Also ceramics and hybrids of metals and ceramics are developed. Apart from composition categories, it is recommended to set materials into functional categories for example materials that are specially intended for use as a pattern in investment or sand-casting applications. It is to be mentioned that the materials are available in many varieties of parameters from very hard to average to rubber like soft elastomers [63].

2.3.1 Plastics

There is a hugely diverse range of materials with ranging properties available in commercial plastic industry which are also deployable in 3D printing as well. The material options in the family of 3D printable materials is quite large as compared to other printable material types. Plastics can be defined into two categories depending upon their behaviours at high temperatures [7].

2.3.2 Thermoplastics

These materials retain their properties even after melting and can be melted, moulded, cooled, and melted again and again without change in their properties [7].

2.3.3 Thermoset plastics

These are permanently set once they are moulded and cannot be re melted. Their setting process in irreversible. The material used in material extrusion systems are solely thermoplastics such as ABS, polycarbonate (PC), a mixture of PC and ABS, and PLA. ULTEM 9085 is a thermoplastic offered by Stratasys. It has a very high strength to weight ratio and a good flame, toxicity and smoke properties. These properties make it very suitable for deployment in aircraft industry. Low-cost material extrusion materials are limited to ABS and PLA until 2012. Taulman3D then introduced a nylon copolymer filament in both 1.75 and 3 mm diameters. Later a clear nylon filament was introduced by the same company as well.

The materials deployed in photopolymer processes are lie in thermoset plastics. These are usually acrylates, proprietary acrylics, or epoxies, and are used usually in all material jetting systems and vat photo-polymerization systems.

One of the most widely used polymer in powder bed fusion processes (laser sintering) is Polyamide (PA). Other materials in polymer category include polystyrene and polypropylene along with carbon, glass and aluminium filled PA powders. The cost of polymers used in 3D printing are usually many folds higher than the corresponding materials deployed in conventional traditional manufacturing processes. Most of the photopolymers and thermoplastic for 3D printing cist within the price range of $175-$250 per kilogram. As compared to the thermoplastics used in injection moulding which typically range from $2-$3 per kilogram. Therefore the 3D printing plastics are around 50-100 times more expensive than the plastics used in injection moulding. [7,61]

2.3.4 Metals

The number of metallic materials available for the 3D printing based systems are becoming greater day after day. Designers can choose the material from a wide range including tool and stainless steel, titanium alloys, nickel/based alloys, commercially titanium, aluminium alloys, copper alloys, cobalt-chromium alloys, gold and silver.

Several manufacturers of metal systems, develop or encourage development of new material from their customers. One of the examples of such a joint venture is Morris technologies (which is now parted with GE aviation) and EOS. Morris technologies produced the 17-4 PH stainless steel to be used in the DMLA systems. Directed energy diffusion distribution and the metal powder based bed fusion processes usually possess the capability of producing parts from the metal materials as listed above. Also mostly the directed energy deposition processes usually support multi-material capability, where two or more powdered materials are possible to combine. Metal parts can be constructed using other 3D printing processes too.

The binder jetting systems from the ExOne Company are capable of producing metal parts consisting of iron, bronze, stainless steel or tungsten along with a bronze infiltrate. In the post-build furnace cycle, the binder burns out and the metal alloys are produced by infiltrating bronze metal into the parts. The ultrasonic 3D printing system by Fabrisonic form metal parts using bond tapes. The choices of the materials include many alloys from titanium, aluminium, stainless steel and copper. Hoganas's binder jet systems produce small parts from stainless steel in which a furnace cycle is needed post-build. Most of the 3D printers systems which build the parts from metal, melt the metals and the resultant product approaches 100% density. While all of the manufactured parts may not be fully dense, the resultant product mostly matches or may even exceed the properties of the cast part of the same material and some also ten to approach the properties of a wrought material. [7,61,63]

2.3.5 Ceramic

Several technologies in 3D printing processes ceramic materials and ceramic blends. Phenix systems developed the ProX bed fusion machines which feature a material from alumina. In 2013 the 3D printing systems acquired Phenix. These systems also offer a ceramic-rein forced photopolymer called as Accura CeraMAX. Some of the binder jetting systems from the ExOne Company make glass parts. Cerafab 7500 is a system from Lithoz GmbH which manufactures parts using its phoro-polymerization process and offers photopolymers filled with zirconia, tri-calcium phosphate or alumina. Ceramic powders are offered by Viridis3D [7,61,63].

2.3.6 Bio compatible Materials

Biocompatible are getting a lot of interest for 3D printing systems. Some of the metals such as as titanium Ti-6AI-4V (grade 5), finds its applications in medical as it can be implanted inside the human body. Another group of material is PEKK (polyetherketoneketone) and PEEK(polyetheretherkerone) that can be implanted. The 3D-bioplotter system is developed by Envisiontec and it lists several materials which are biocompatible. The technology build from sheet lamination by Mcor develops parts made from an adhesive and paper. The parts built from this system have the impression of wood. These parts can be hardened using cyanoacrylate and finished by using sanding and painting procedures [7, 61, 63].

2.3.7 Composites

The composites are created when a new material is added to the raw base material. One of the commonly used base materials in powder bed fusion systems for composites is polyamide (nylon). The filling material include aluminium, glass and carbon fibres. Adding filler materials have several advantages. They improve the properties of materials like hardness, tensile strength, or rigidity. But the fibres do not cross from one layer to the next layer therefore, most of the improvements are 2D (xy) only and z direction is unaffected. The registered powder used in 3D printing systems binder jetting systems by Projet is regarded as a composite but in actual its formula is known to be solely a powder based on plaster [7, 61,63].

2.4 Basic working principal of 3D printers

The processes of 3D printing seems simple at first glance. Given below are some of the steps that users follow:

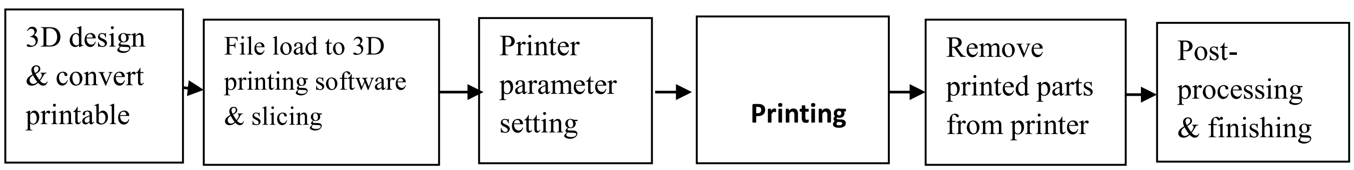


Figure 2-1: Basic flow diagram for 3D Printing

The major steps involved in this process are

i. The first step is the component modelling. This is usually achieved by using CAD software. Using this software the designer reconstructs the dimensions and geometry of the desired component. Alternatively a scanner can be used.

ii. The next step involves preparing the prints. At this stage the software creates the G-Code that is a code with coordinates. The machine uses the code to direct the nozzle for deposition of materials onto the bed.

iii. Next step is printing and testing the manufactured part. The design needs to be thoroughly thought out according to the material specifications. If the desired design is not achieved then the CAD design, material used and the type of printer in use can be updated for the desired specific results.

2.5 Details about Polymer based 3D Printing Technologies

Table 2-1: Commonly used specific 3D printing technologies for polymer based product

Serial	Technology Name	Description	Popular Brand Name
01	FDM (Filament based)	Fused deposition modeling; also called FFF(Fused filament fabrication)	Prusa, Reprap, Karika, Zortrax, Ultimaker etc.
02	DLP SLA	Digital Light Processing Stereolithography	Flashforge Hunter, Kudo3D Titan 2 HR
03	BINDER Adhesive TYPE	It is also called Binder Jetting	ProJet MJP 5600
04	LCD SLA	Liquid Cristal Display Stereolithography; Also called Laser based SLA	Zortrax Inkspire, Prusa SL1
05	SLS	Selective Laser Sintering	DynamicalTools ST30, FormlabFuse1, SharebotSnowwhite
06	LOM	Laminated Object Manufacturing	Solido3d, EnvisionTEC, Mcor
07	Material Jetting	Also called DoD (Drop on Demand)	ProJet, AMpolar i2
08	Photopolymer Jetting (PJ)	Photopolymer Jetting	Polyjet, HP Multi Jet Fusion
09	FDM (pallet based)	Fused deposition modeling; Material comes directly from pallet	Titan Robotics
10	CLIP SLA	Continuous Liquid Interface Production Stereolithography	Carbon3D

2.5.1 Pallet Based FDM Technology

FDM 3D Printer Pallet Extruder is the major component in 3D prints where it feeds thermoplastic to the exchanger zone to melt down towards the nozzle, thin layered material extrude is subjected towards the surface plate. It is a horizontal built extruder with auger bit, heat exchanger, horizontal guiding system and a motor. Polymer ABS is typically used thermoplastic material for injection molding applications, for the ease of manufacturing which is very predominant in nature. The melting point of ABS is 200^0C to 220^0C, so we adopt steel F-174 as extruder material so as to withstand the melting temperatures. Single or double screw extrusion system plastic granules are fed into the auger bit heat exchanger to melt the plastic into a molten state so as to push the extrusion process; which is connected to a battery it works according to the given volumetric flow & melting temperature of the input material. Schematic diagram of Pallet based FDM technique [43].

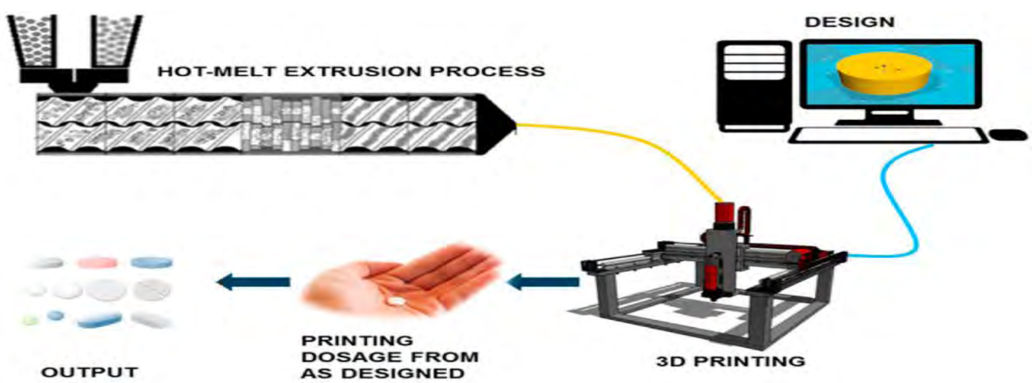


Figure 2-2: Flow diagram for Pallet based FDM Technology; source:

The **ATLAS™** is Titan Robotics' flagship industrial grade FDM pallet based 3D Printer. Available with pellet extrusion, filament extrusion or a hybrid pellet + filament extrusion system, the Atlas 3D Printer provides solutions for your additive manufacturing needs by using pallet instead of printing filament. Pellet Extrusion increases the speed at which parts can be created, cutting down production time by a factor of 10X (10 times). The number and types of materials that can be 3D printed is greatly expanded, enabling the use of custom compounded materials, from very soft rubber plastics to strong, high temperature or carbon-fiber filled plastics, multi-color materials etc. [44].

Figure 2-3: Pallet based FDM 3D Printer; Source: Titan3D

2.5.2 Filament based FDM 3D Printing

Filament based FDM 3D Printing is a 3D printing process that uses a continuous filament of a thermoplastic material such as ABS, ASA, PLA, ASA etc.. Filament is fed from a spool through a moving, heated printer extruder head, and is deposited on the growing work which has shown in figure 2-3. The print head is moved under CNC control to define as per the design printed shape. Usually the print head moves in two dimensions to deposit one horizontal plane/axis, or layer; the work or the print head is then moved vertically by a small amount to start a new printing layer. The speed of the extruder head also controlled to stop and start deposition and form an interrupted plane without stringing or dribbling between each sections of the machine [60].

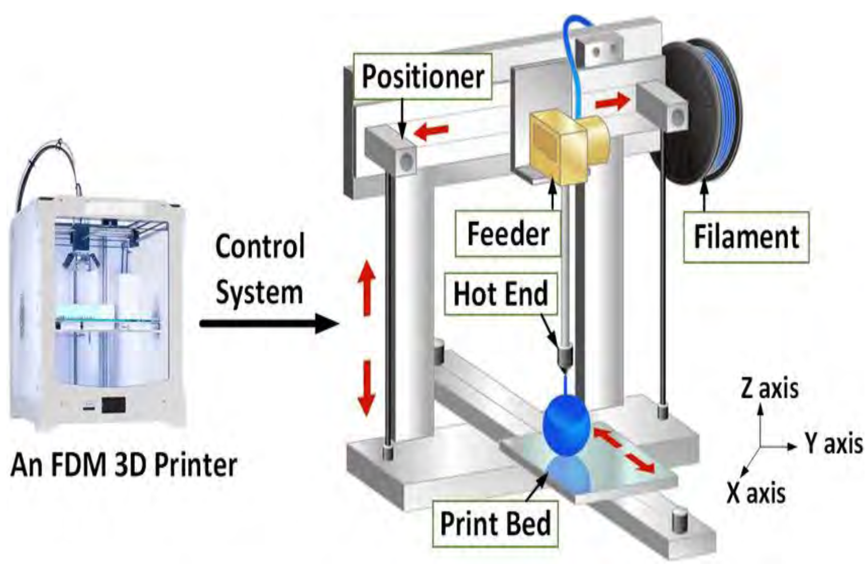


Figure 2-4: Mechatronic structure of an FDM 3D printer and flow diagram; Source: Ultimaker.com

2.5.3 Photopolymer Jetting (PJ)

Almost Inkjet type print heads are used to jet liquid photopolymers onto a build platform. The material is immediately cured by UV lamps and solidified which allows to build layer by layer. Several materials can be jetted at the same time of curing process. Photopolymer jetting requires support structures for overhangs parts buildng, which is usually built in a different material. It is also called Polyjet modeling, multijet modeling, polyjetting, multijetting, jetted photopolymer etc. [53].

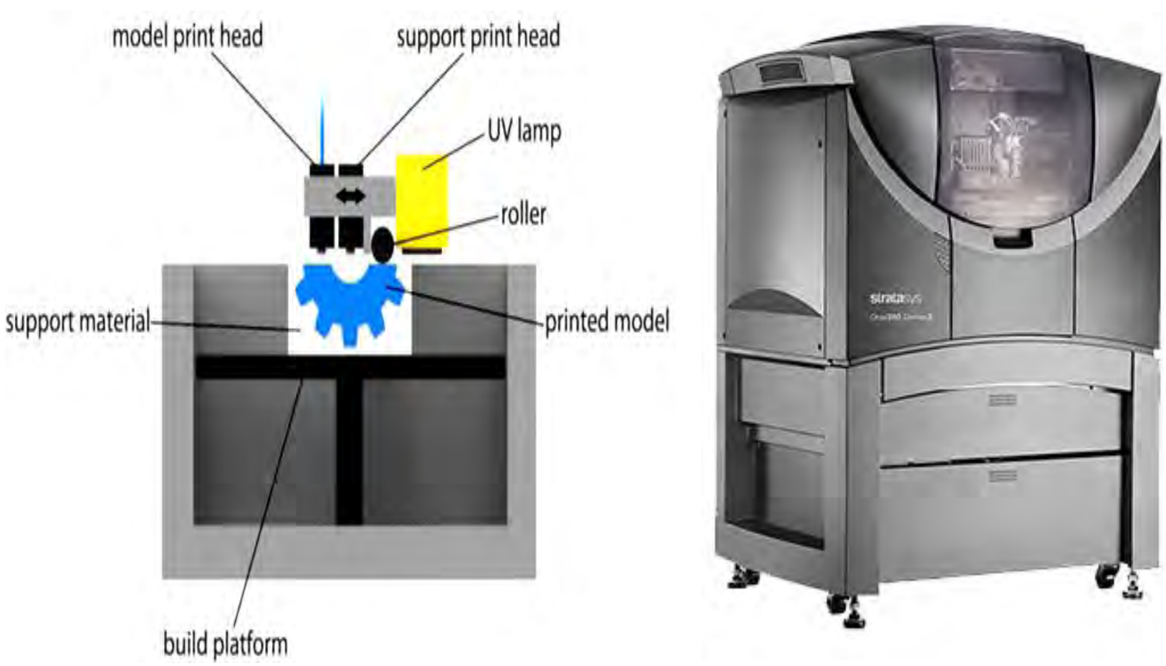


Figure 2-5 : Flow Diagram for Photopolymer Jetting and Polyjet printer; Source: Startasys

PolyJet is a superb 3D printing technology that produces smooth, accurate parts, prototypes and tooling but price is too much high. With microscopic layer resolution and accuracy down to 0.014 mm, it can produce thin walls and complex geometries using the widest range of materials available with any 3D printing technology [52]. PolyJet 3D Printers jet layers of curable liquid photopolymer onto a build tray can creating exceptional detail, good strength, strength surface smoothness and precision [52,53,54].

2.5.4 Stereo-lithography (SLA)

This process produces an inexpensive and accurate duplicate of any component in plastic. These components are not usually functional pieces, but are used for engineering models or design aids. For example stereo-lithography SLA replicas of metal castings can be used in verifying tool paths or machining patterns before the cutting of expensive metal cutting process. These SLA components are constructed using a photosensitive liquid resin, which is exposed to an ultraviolet laser to form a solid surface. The parts are scanned over the surface of the resin. Once the scanning is done. The constructed platform is lowered under the surface of the resin and the procedure is repeated again. Once this process is complete, the part is brought out of the liquid resin, cleaned and then fully cured. SLA was undoubted leading process in early development years of additive manufacturing technology after the 3D systems were commercialized in 1988. SLA machines are still being manufactured, although unit sales are on decline with the arrival of new processes. Many of these systems from Envision Tec GmbH deploy a lamp or a source of LED and the digital light processing (DLP) for curing photopolymer. The DLP have advanced with the years and resolutions have become higher and parts are finely featured [63].

Available Categories SLA:

- **DLP SLA (Digital Light processing Stereo-lithography)**
- **CLIP SLA (Continuous Liquid Interface Printing Stereo-lithography)**
- **LCD SLA (Liquid Crystal Stereo-lithography)**

2.5.5 DLP SLA (Digital Light processing SLA)

DLP SLA is similar type of Vat polymerization. Vat polymerization is a 3D printing technologies make use of a (liquid) photopolymer resin which capable to cure (solidify) under a light source. Naturally, both use resin and a light source to produce parts, the main difference being the type of light source which is used to cure the resin.

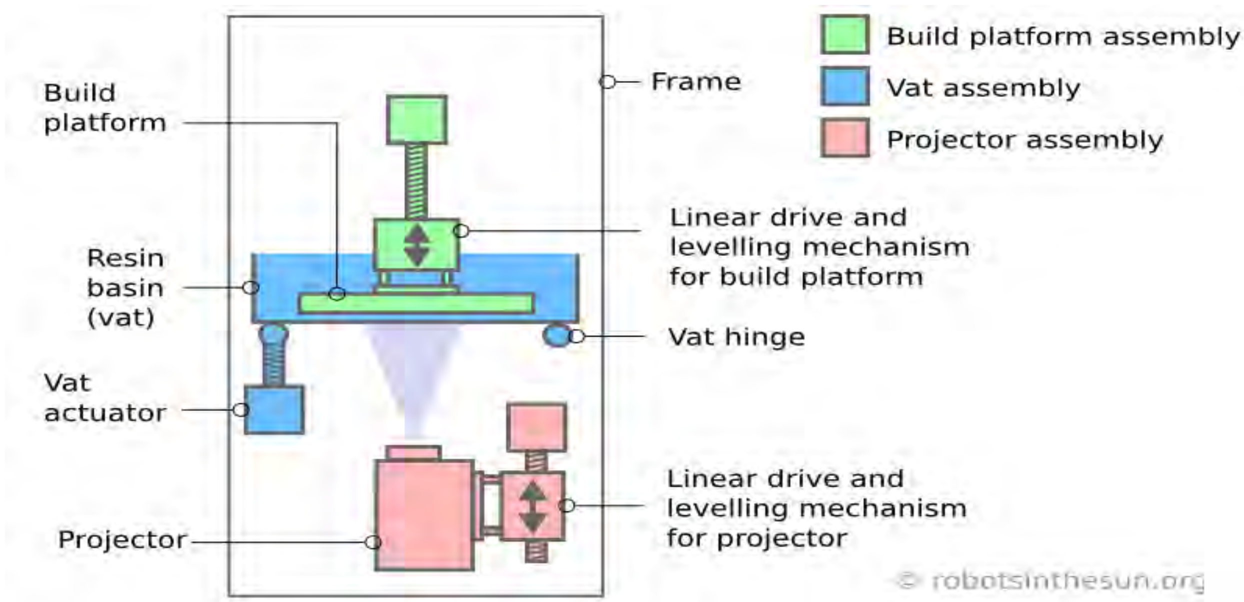


Figure 2-6: Flow diagram for DLP SLA ; Source: robotsinthesun.org

Desktop DLP 3D printers are built around a resin tank with transparent bottom and a build platform that descends into a resin tank to create printed parts upside down, layer by layer [54,56]. Taiwan-based Young Optics has been manufacturing high-quality commercial DLP desktop 3D printers since 2012 under the brand name MiiCraft. They have primarily manufactured very small scale 3D printers with small build envelopes, even producing the world's smallest DLP 3D printer the MiiCraft+ last year [57, 51, 52].

Figure 2-7: MiiCraft+ DLP 3D printer; source: Miicraft

2.5.6 CLIP SLA (Continuous Liquid Interface Printing Stereo-lithography)

Continuous Liquid Interface Printing is a proprietary way of 3D printing that uses almost similar photo polymerization to build smooth-sided solid objects of a wide variety of complex shapes using resins. It was invented by Joseph DeSimone, Alexander and Nikita Ermoshkin and Edward T. Samulski and was originally owned by EiPi Systems which is now being developed by Carbon^{Tm} 3D printer manufacturer. The CLIP method uses ultraviolet light to harden a photosensitive resin while the fabricated object is drawn up out from the resin bath. The continuous process starts with some pool of liquid photopolymer resin. Part of the pool bottom is transparent for ultraviolet light passing. An ultraviolet light beam shines through the window, illuminating the precise cross-section of the object to visualize. The light causes to solidify the resin. The object rises slowly to allow the resin to flow under the platform and maintain contact with the bottom of the object. An oxygen-permeable membrane lies below the resin, which creates a persistent liquid interface layer which preventing the resin from attaching to the window [45-48].

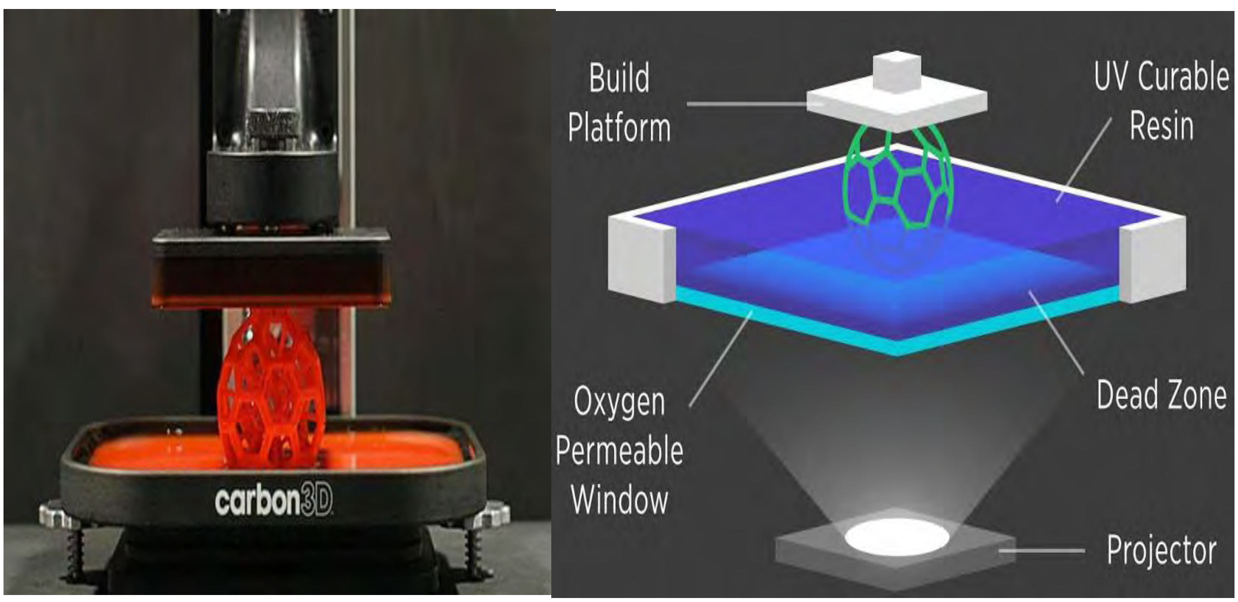


Figure 2-4: CLIP flow diagram [49] & Carbon 3D printer [50]

Digital Light Synthesis—enabled by Carbon's proprietary CLIP™ process—is a breakthrough technology using digital light projection, oxygen permeable optics, and programmable liquid resins to produce parts with excellent mechanical properties, resolution, and surface finish [50].

2.5.7 LCD SLA

As for LCD 3D printing, the process is nearly similar to DLP in that it utilizes projected light bunch of LED to solidify resin layer-by-layer until a 3D model is built. The main difference is that LCD 3D printers use a bank of UV LEDs to project light through a mask of the layer on an LCD panel whereas DLP 3D printers utilize an array of micro-mirrors (each mirror corresponding to a pixel) to either project light, or not, thus creating a mask to build the object.

In general, LCD 3D printers are made by cheaper components than DLP 3D printers, making them a cheaper resin 3D printing solution, that’s why it’s called economic version of SLA. This is a great thing because it extends the reach of resin 3D printing to a huge amount of customer. Both DLP and LCD are able of achieving fast print speeds and great details, but as the price tag grows, the DLP 3D printers start to trump their LCD counterparts [57].

Figure 2-8 : Prusa SL1 LCD SLA 3D Printer; Source: Prusa Research

2.5.8 Material Jetting (MJ)

This material jetting process uses inkjet-printing heads and deposits tiny droplets of the building material. These droplets are distributed selectively as the printer heads move through the object building area. The substances used in this process are usually wax-like materials or photopolymers. These type of materials are used because they can be deployed as investment casting patterns. The material jetting systems often employee multi-nozzle print heads in order to increase build speed and printing different materials. One material is used for creating support structures while another is used for building the material. These systems have the capability to print multi-material and graded materials objects.

Material is jetted onto the build surface or platform, where it solidifies and the model is built by layer by layer adhesion which is very close similarity with Photopolymer jetting. Material is extruded from a nozzle which moves horizontally across the build platform. Machines vary in complexity and in their mechanism of controlling the deposition of material. The material layers are then cured or hardened using ultraviolet (UV) light. Multiple materials can be used in one process and the material can be changed during the build stage. Material is jetted onto the build platform surface in droplets, which are formed using an oscillating nozzle. Droplets are then charged and positioned onto the surface using charged deflection plates. This is a continuous system which allows for a high level of droplet control and positioning. Droplets which are not used are recycled back into the printing system. Support material can be removed using a sodium hydroxide solution or water jet. Due to the high accuracy of the process technology, the level of post processing required to enhance the properties is limited and the functional and aesthetic qualities of a part are largely determined during the printing stage [54].

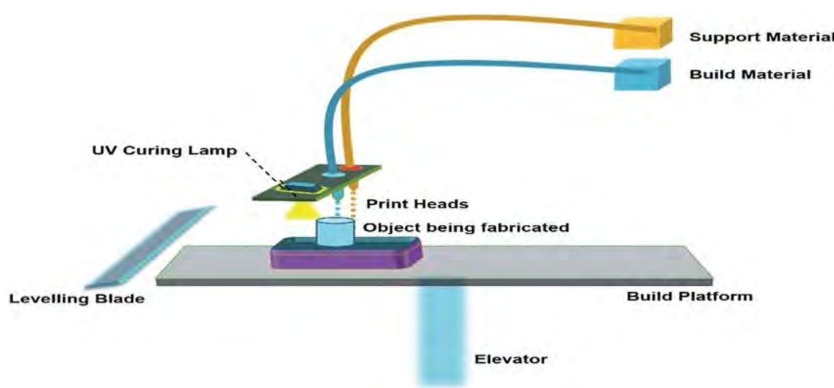


Figure 2-7: Flow Diagram for Material jetting

2.5.9 LOM (Laminated Object Manufacturing)

It is defined as a process which bonds the sheets of raw material to form an object. Sheet materials can consist of metal tapes and foils that form metal parts or adhesive –coated papers that create a ply-wood like solid material when laminated into a 3D object. Helisys developed the first sheet lamination technology based on laminated object manufacturing (LM) on commercial scale. It used an adhesive coated on one side of a roll of craft paper and heated roller for the lamination of successive layers on the other side.

Ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM) is the part of Sheet lamination process. The Ultrasonic Additive Manufacturing process uses sheets (plastics, papers, rubber) or ribbons of metal, which are bound together using ultrasonic welding. The process sometime does require additional CNC machining and removal of the unwanted materials, often during the welding process. It uses a cross hatching principal during the printing process to allow for easy removal post build. LOM are often used for aesthetic and visual models and are not good for structural use. [51, 57]

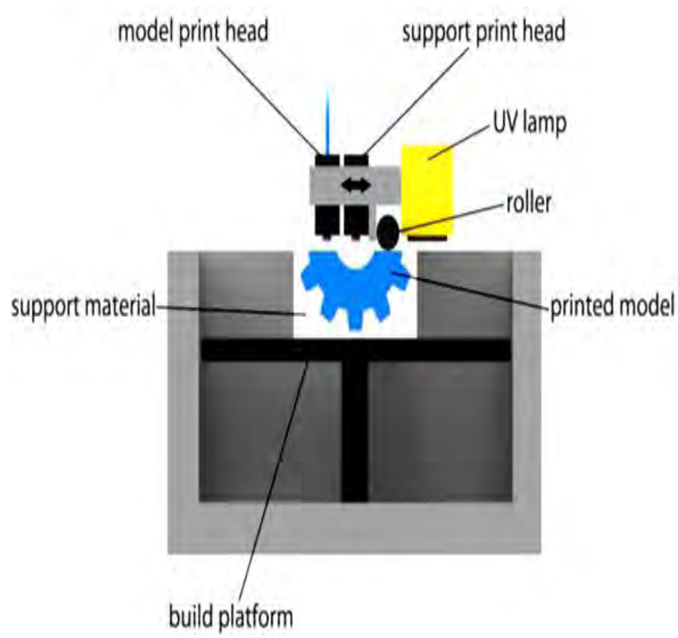


Figure 2-9: Flow diagram for LOM production process

Figure 2-10: LOM based Mcor 3D Prinetr; Soure: Mcor

2.5.10 Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is an Additive Manufacturing process which is belongs to the Powder Bed Fusion category. In SLS process, a laser selectively sinters the particles of a polymer powder, fusing them together and building a part layer-by-layer. The materials used in SLS are thermoplastic type polymers that come as a different types of granular form.

SLS finds its applications in making functional plastic components. SLS is a technique that uses a laser as the power source to sinter powdered nylon or polyamide type material, aiming the laser automatically at points in space which is specified by a 3D model, binding the material together to create a solid structure. SLS is similar to Selective Laser Melting (SLM); both are developed based on the same concept but differ in technical details. [57, 51]

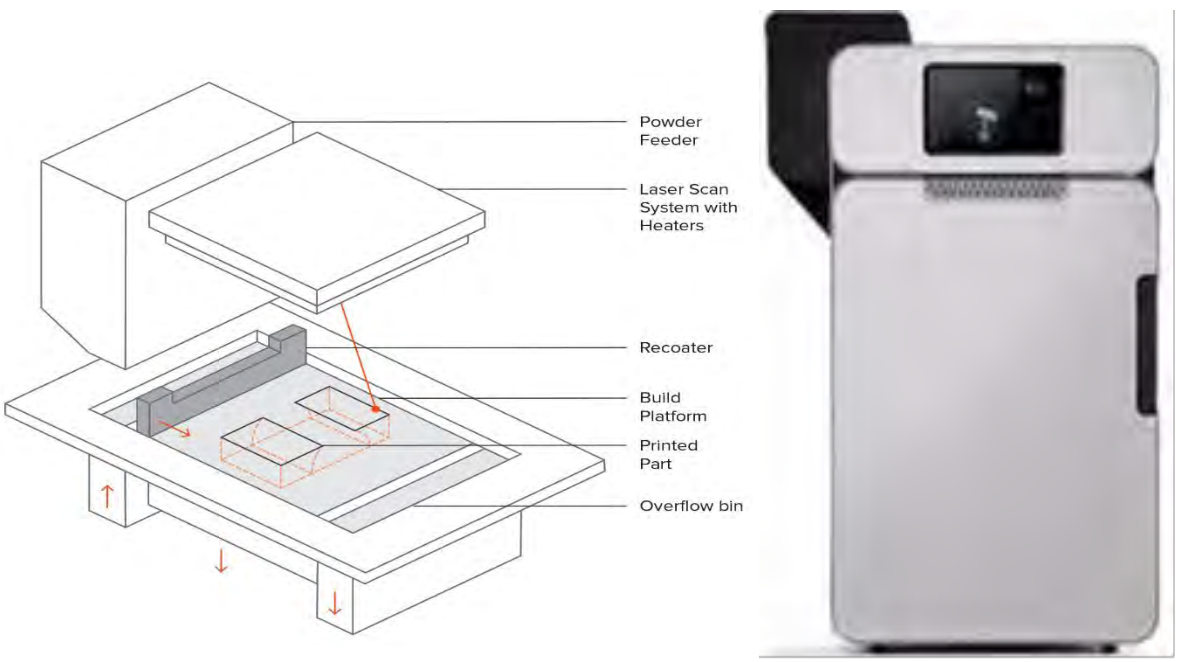


Figure 2-11: Flow diagram for SLS process & Formlab SLS 3D printer; Source: Formlab

2.5.11 Binder Jetting or Binder Adhesive type

The Binder Jetting (BJ) or Binder Adhesive type is a process in which a liquid binding is deposited selectively using an inkjet print head nozzles to merge materials in powder form in a powder bed. Binder jetting and metal jetting are similar as they both use inkjet printing process to dispense the material. The difference between the two techniques is that in binder jetting the distributed material is not the built material. It is rather a liquid that is distributed onto a bed of powder so that the powder is held in the required shape. The data from computer is translated into the moulds, which are built from sequential layers of sand to be filled metal in melted state to make functional prototype pieces. A layer of sand and activator is mixed and applied to the entire building platform. After that, a print head is used to deposit a binding mixture the layer of the sand. The activator and the binder combine and get hardened resulting in the creation of a sand mould, layer by layer from bottom to the top. Excess sand is removed and then the mould is ready to be filled with molten metal o be used in casting the pieces of prototype.

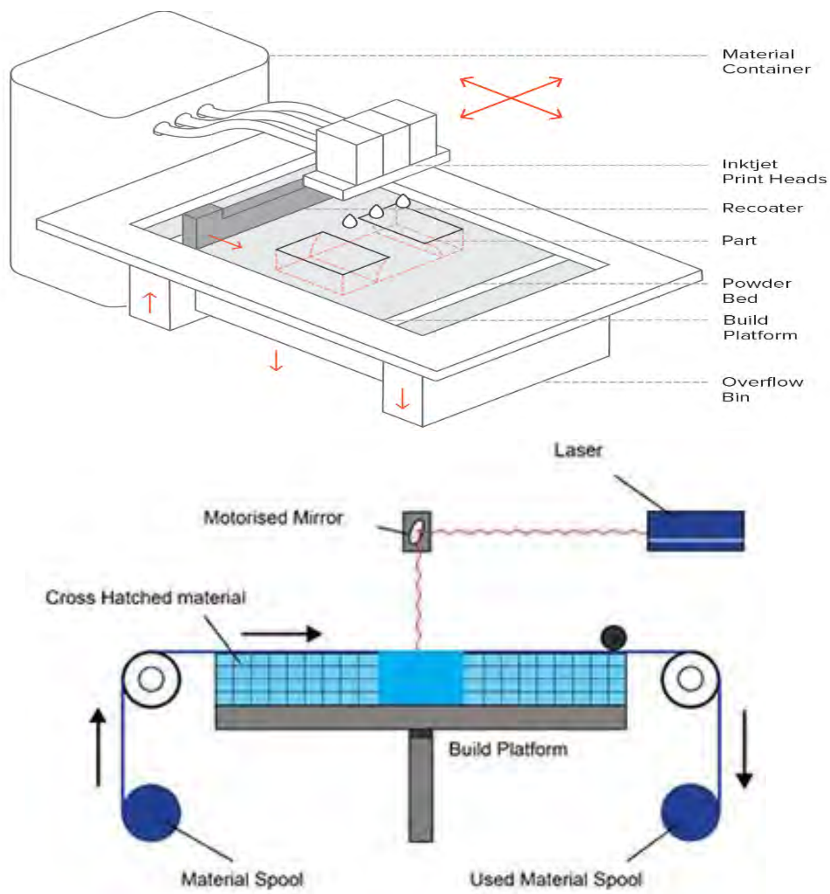


Figure 2-12: Binder Adhesive type process flow diagram

Figure 2-13: Binder Adhesive type 3D printer ProjetMJP600 ; source: 3dsystem

2.6 Multiple-criteria decision-making (MCDM)

The Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA) belongs to the operations research discipline and it specifically assess multiple contradictory criteria in decision making. They fins applications in daily life as well as business, medicine and government. The contradictory criteria which are typically used in evaluating are cost and quality. These criteria are easily conflicting with each other.

In our routine lives, we indirectly weigh multiple criteria and are calm with the results of such decision based on intuition only [7]. On the other hand, if high risk factors are involved and critical decisions are to be made, it is essential to organize and understand the problem and evaluate every criteria explicitly. For example. In case of building a power plant or a nuclear reactor not only very complex design factors are involved, but also multiple sectors are getting effected by the project.

Organizing the complex problems efficiently and taking in to account multiple criteria leads to more informed and better judgments and choices. This field has shown remarkable advances since it was first introduced in early 1960s. There are numerous specialized decision making software [8, 9]; which help in implementing multiple approaches and methods and find their applications in numerous areas like politics, business, energy and environment to mention a few [10].

MCDM in related to structure and solve problems including multiple complex criteria related to decision making and planning. The purpose of the technique is to facilitate decision makers in confronting such issues. Usually there is no exclusive optimum solution for these problems and in it important to take help from decision-makers choices to distinguish between the solutions.

The term “solving” can be inferred in many different means. It can be choosing the “best” option from a set of many available options where the “best” can be seen as the most relevant or preferred option as suggested by a decision-maker. Another definition of solving may be choosing a set of good options, or grouping the available options into different sets w.r.t preference. Another definition may be to find all the efficient available options.

Most of the MCDM applications include creation and application of weighted sum models which is also known as the points system. It consists the explicit weightage of multiple criteria and scoring them accordingly.

2.6.1 Analytic Hierarchy Process (AHP)

This technique is used in making complex decision based on psychology and mathematics and it is a structured technique used for organization and analysis. It is one of the most accurate technique for computing the relative weights of criteria. The experiences from individual experts are utilized to approximate the relative magnitude of different factors using pair-wise comparisons. Each of the expert has to compare the relative importance of the two different items using a questionnaire specially designed for this purpose.

AHP finds it applications in group decision making [8] and is employed globally in numerous decision making situations in various fields like business, government, healthcare, industry, education and ship building [9].

Instead of one unique optimal decision, the AHP technique helps the decision makers to find the “best” solution according to their goal and the nature of the problem. This technique provides a broad, comprehensive and balanced framework for organizing a decision problem, for the representation and quantification of its related elements, for establishing a relationship between these elements and the goals, and for the evaluation of alternative options.

Some of the situations where this technique can be applied are [11]

- Resolution of conflicts: settlement of disputes between different parties who apparently have mismatched goals and position [8]
- Bench marking: comparison of the process in personal organization with other state of the art organizations.
- Choice: in order to select one best solution among a set of given solutions, typically when there are more than one complex criteria are involved in decision making.
- Prioritization: among the pool of a suitable solution, determine the relative worth of the members of the pool in contrast to choosing the best option or just ranking them.
- Ranking: placing the members of the set of solution in the order of most to least worthy.
- Quality management: deal the m multidimensional characteristics of quality and improve the quality.
- Resource Allocation: Distributing the available resources between a set of available options.

This work has used MCDM-AHP for its analysis because the number of criteria is thirteen which is quite high. Also the number of alternatives or options to choose is 8. It is very difficult to carry out analysis with this much number of alternatives apart from MCDM-AHP the questionnaire involved in the study is quite lengthy and extensive. In order to check the authenticity of data AHP is one of the best techniques. The consistency of data from each of 10 experts can be checked very easily using the AHP technique. Using the MCDM-AHP technique not only gives the benefit of choosing the best available option but also rank all the options from a pool of options. Lastly, it is easier to carry out pairwise comparison of the criteria using AHP.

2.7 The Triple Helix Model of Innovation

The Triple Helix Model of innovation denotes a series on interactions between the industry, government and academia. The purpose of the model is to nurture social and economic development as described by the concepts of knowledge society and knowledge economy [24, 25, 26]. The theory of innovation helical framework, represents each sector as a helix or circle where overlapping areas represent the interactions between the sectors. Over the time, the modelling has evolved and can now represent more complex interactions than a 2D representation. The theory of this framework was first presented by Henry Etzkowitz and Loet Leydesdorff in the 1990s [27].

The interactions between the government, universities and the industries has given rise to creation of intermediate institutions such a science parks and the technology transfer offices. Etzkowitz and Ledersdorff brought forward the relationship between these different sectors and clarified the creation of the new fused organizations [28]. This innovation framework is now widely deployed and used by the policy makers to help in transforming each sector [29, 30, 31].

2.7.1 Components of the model

The three major components of the model are

- Academia industry interactions
- Academia government interactions
- Government industry interactions
- Strength of interaction

This model of innovation is based on the interaction between the three major elements and their related roles in the initial steps as theorized by the authors Etzkowitz and Leydesdorff [32]. The universities carry out the basic research, the industries produce commercial goods and the governments regulate the markets [25]. As the collaborations and dealing rise within the framework, each basic element adapts some of the characteristics of the other elements resulting in the creation of hybrid institutions. Mutual collaborations exist between the universities, industries and government.

2.7.2 Academia Industry interactions

The authors Etzkowitz and Leydesdorff are of the point of view that the initial preliminary role of universities is to facilitate research and education to individuals. Hence the interaction between the university and industry initially depends majorly on these two elements. In a linear model of innovation, the universities are meant to carry out research and the industries will work on the delivered research to produce novel commercial goods.

The other form of interaction is the involvement of the university faculty and managers in industry. Etzkowitz says that the interaction of people between the industrial sector and the universities establishes a very efficient knowledge transfer. This can lead to a long lasting move to one direction or in other scenarios the entire career spent in between the two helix. There are many examples of research directors in industry who join universities while still continuing their industrial involvements [25]. However there are other scholars who have a point of view that if faculty members are involved in consultation services to the industry, it may have many drawback like a reduced attention to students education and the potential contradiction of interests related to the use of the resources provided by university for the assistance of industrial sector [33].

Another transfer of knowledge between the educational and industrial elements takes place through informal communications, interest of industry in university publications and conferences [34].

One more form of interaction is the cooperative programs which is intended to integrate an industrial approach into the student study curricula e.g., the MIT-General Electric course [35].

2.7.3 Academia Government interactions

The power of the mutual interaction between the universities and the government depends upon the general attitude and policies of the current government with respect to the higher education. Etzkowitz and Leydesdorff's define the degree of these interactions using a spectrum. On one hand are the public universities like those in continental Western Europe, the government has a great influence on university operations and the research they carry along is the major source of income [29]. On the other hand at the end of spectrum, typical universities of United State are present, who still get some funding from the government but over all have a higher level of independence from influence of government. However, these two ends of spectrum are extreme and ideal-type and may not essentially reflect the actual realities [13]. The current situations and hanging circumstances can persuade the government to have closer bond with the academic sector for example in wartimes for defence related research, or physics research. For example during the World War II and the Cold war the United States extensively funded the area of physics [14].

2.7.4 Government Industry interactions

The level of relationship between the industry and government depends upon the current government's attitude and plans towards the market. The role of government in liberal economies is merely preventing the market failures. On the other hand, if the government has a better interest in the market, it works for to regulate the industry. These two scenarios are again the same as before that they are the extreme ends of a spectrum and there is a lot of room for extensive variations based on current affairs, circumstances and the disciplines [29]. For example, Bhaven Sampat stated that the government generated a law to avoid patenting from or awarding licence to the industries based on university research supported financially by the National Institutes of Health [35]. One of the major roles of the government with regards to its relationship with industry is the creation of laws for intellectual properties and its enforcement.

2.7.5 Strength of interaction

Etzkowitz and Leydesdorff mentioned in his research that the strength of the ties among universities, government and the industry is subjected to the component which is the major driving force in the entire framework. The driving factor among the three elements for interactions is the strong state in a top-down fashion in a statist model [42]. In this way stronger ties and more integrated models are created. The model based on laissez-faire studies, the leading forces are the industry and related markets. In this case the ties are not very strong and each element i.e. government, industry and universities remain quite independent. The strength of ties between these elements can also vary depending upon the growth of a country. A silo model dominates in a country which is under developed. The developing countries have moderate ties due to push pull model where economic growth is the push and the competitive technological development driven by the market causes the pull. The countries which are developed have strong ties in the form of science parks, technological fairs etc [36]. Recent studies by Etzkowitz emphasize that the modern shift towards a society based on knowledge has given relatively bigger roles and contributions to the universities [37]. Definitely, as the innovation is progressively based on the scientific knowledge and advancements, the universities are being more valued as a creator of knowledge. In conclusion the author claims that the government, university and industry are mostly equal [28] and that no specific element is essentially the motivating force behind the triple helix model of innovation.

2.7.6 Triple helix for policy making

The triple helix model of innovation which helps to visualize and analyse the evolving relationships between industry, university and government [26]. However, it can be used as a tool for policy making according to Etzkowitz and Leydesdorff. The model has been deployed for both purposes by the government organizations in United States like the United States department of energy [38]. The author claims that when the Soviet era ended, Eastern Europe deployed the Triple Helix model for policy making to promote the growth rate. Whereas in Sweden, the same model was used to tie together the innovation initiatives of different scales to improve their performance efficiency [28, 29]. This model also finds its application in numerous developing regions and countries [31].

2.7.9 Criticism of the model

Many research scholars have criticised the triple helix model as a policy making tool in regional development and economic growth [26]. One of the arguments is that the framework by Etzkowitz and Leydesdorff's was founded in developed western countries, where there is a specific infrastructure and particular circumstances only. For example the model assumes by default that the activities which are intense in knowledge are linked to the economic development, that rights of intellectual property are secure and protected, and the government has market oriented and democratic vision [39]. In addition, the criticism of this model emphases the circumstances that empower the deployment of an innovation policy based on triple helix models [40, 41]. Hence according to the scholarly critics, the model under study cannot be implemented for policy making in the developing regions or countries where any of these conditions is not available. However there are other scholars who are of the view that the proposed model has the capability to describe the situations in developing countries as well and is useful tool for planning policy also [31].

2.8 Evaluation of Financial Feasibility

Return on investment—sometimes called the rate of return (ROR)—is the percentage increase or decrease in an investment over a set period. It is calculated by taking the difference between current, or expected, value and original value divided by the original value and multiplied by 100.

IRR is a metric that doesn't have any real formula. It means that no predetermined formula can be used to find out IRR. The value that IRR seeks is the rate of discount which makes the Net Present Value (NPV) of the sum of inflows equal to the initial net cash invested. Companies use this metric for capital budgeting estimates and to assess the profitability of potential investments. Also, the firms calculate the IRR when undertaking expansion plans or setting the budget. The mechanism helps companies to decide the project in which the investment should be made. Simply put, IRR is the discount rate that makes the net present value of all the cash flows from a specific project as zero. Formula for ROI & IRR are: [68]
In case of IRR: Current investment –Future NPV@IRR rate = Zero

In Case of ROI :[(Expected value – Original value)/Original value] x 100

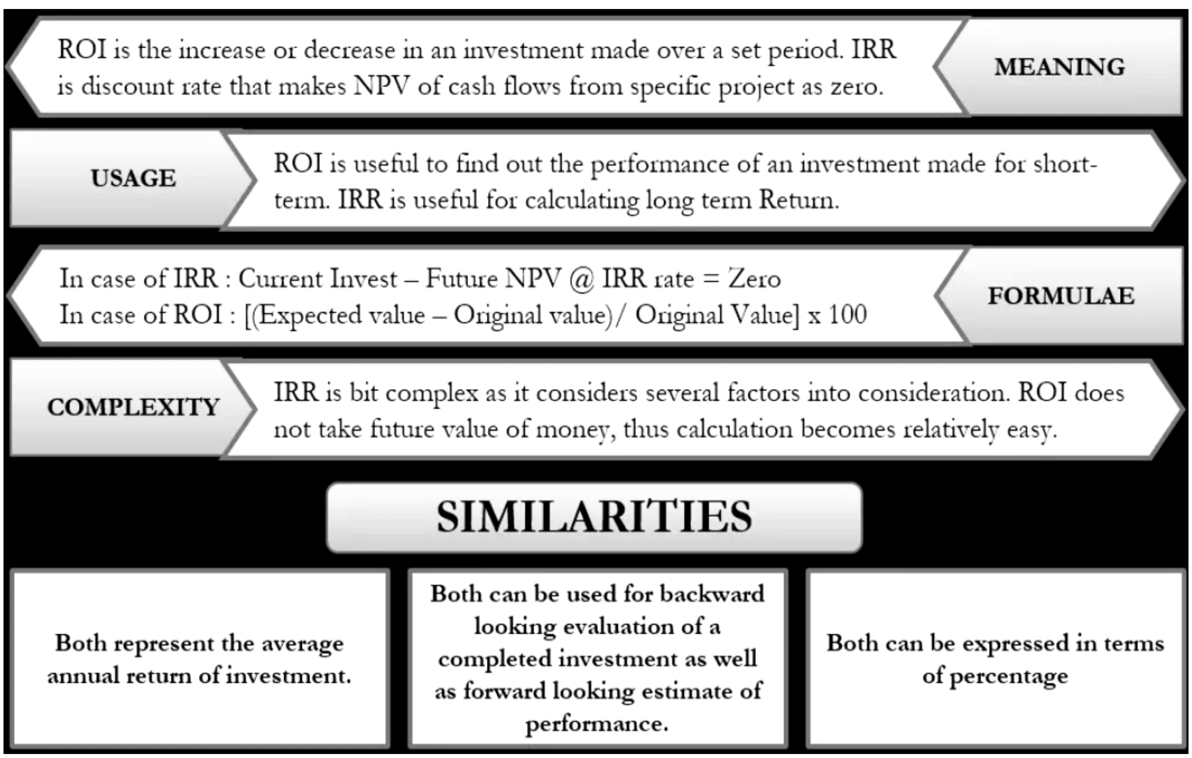


Figure 2-14: Definition and difference between IRR & ROI; Source:efinancemanagement.com

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

My thesis work followed some specific methods and processes which has been divided into few sub-sections. In this study I am following the below steps:

1. The survey was conducted by a structured questionnaire and datasheet.

2. Quantitative and qualitative data were collected by arranging face to face interviews. Interviewees were entrepreneurs, technical personnel, consultants, University professors and related personnel of Additive manufacturing industry.

3. This data is collected to perform Multi-Criteria Decision Making (MCDM) methods. Among the different types of techniques collected data analyzed through AHP techniques.

4. Based on the selected criteria most suitable solutions were addressed.

5. After that financial feasibility has been proceed based on previous case study of solutions for different types of industries.

6. The recommendation was given based on the final result of AHP method and financial feasibility study which will be helpful for implanting the technology by following triple helix model of Academia, Government and Industry interactions.

3.2 Questionnaire

For the selection of most suitable technology and implementation recommendation one set questionnaire was used. Sample of questionnaires has been attached in Appendix A. Based on the interviews and interaction with the relevant experts, observation, and literature review thirteen major criteria has been selected to deploy the 3D printing technology in Bangladesh. Priority was calculated among the thirteen major criteria for individual expert. Further progress of this study will be based on the followings:

I. Dimensional Accuracy
II. Mechanical properties
III. Manufacturing cost
IV. Build volume

V. Ease of Post-processing
VI. Raw material Availability
VII. Technical know-how
VIII. Initial setup cost
IX. Technology maintenance
X. Safety & Risk level
XI. Low Energy consumption
XII. Material variety
XIII. Production rate

The second part of the first phase questionnaire dealt with the pairwise comparisons of alternatives from the criterion. The alternatives are

01 FDM (Filament based)
02 DLP SLA
03 BINDER Adhesive TYPE
04 LCD SLA
05 SLS
06 LOM
07 Material Jetting
08 Photopolymer Jetting (PJ)
09 FDM (pallet based)
10 CLIP SLA

The scale used to find pair wise relative importance is nine-point Saaty(1980) scales as follows: Experts are allowed to add any scale between 1 and 9

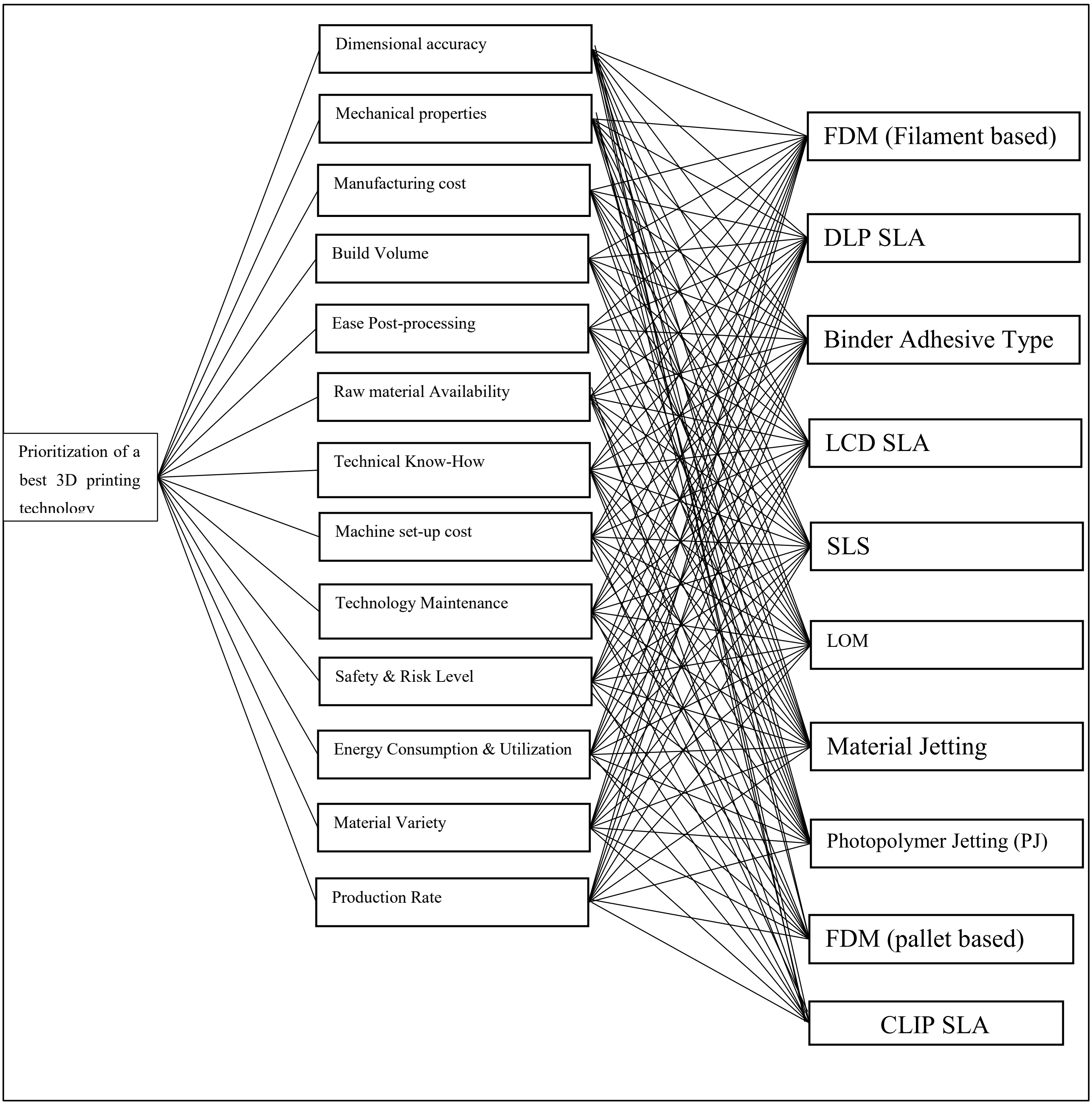
(1) Equally important/preferred
(3) Moderately important/preferred
(5) Strongly important/preferred
(7) Very strongly important / preferred
(9) Extremely important/preferred.

Interviewees were requested to answer the questions with Numerical Rating from AHP Priority Setting.

The objective of the second phase questionnaire was to find out a priority ranking of selected polymer based 3D Printing technology.

In the following diagram showing the interrelation between criteria and alternatives for the purpose of prioritization of a best 3D printing technology:

Table 3-1: Criteria & Alternatives for prioritization of a best 3D printing technology



3.3 Data Collection

First and Second phase data are collected from face to face interview of entrepreneurs, technical personnel, consultants, University professors and related personnel of Additive manufacturing industry. Total of Fourteen personnel is interviewed, among the interviewers 10 experts answer has been accepted.

3.4 Decision-Making Technique

When the benefits of actions are unpredictable, when relationships between variables maybe not only non-linear and stochastic but also actually unknown, the principle of standard optimization for decision-making will not help much. This is exactly the situation we face in the world of today.

Decision-making can be considered as the choice, on some basis or criteria, of one alternative among a set of alternatives. A decision may need to be taken on the basis of multiple criteria rather than a single criterion. This requires the assessment of various criteria and the evaluation of alternatives on the basis of each criterion and then the aggregation of these evaluations to achieve the relative ranking of the alternatives with respect to the problem. The problem is further compounded when there are several or more experts whose opinions need to be incorporated in the decision-making. Lack of adequate quantitative information leads to dependence on the intuition, experience, and judgment of knowledgeable persons called experts.

We can define a generic decision-making problem as consisting of the following activities:

► Studying the situation

► Organizing multiple criteria

► Assessing multiple criteria

► Evaluating alternatives on the basis of the assessed criteria

► Ranking the alternatives

► Incorporating the judgments of multiple experts.

3.5 Multi-Criteria Decision-Making Problems

Making decisions is part of human life. Nevertheless, making a good decision is not always easy in the situation of today's world. This is mainly because there are many contributing factors (multiple criteria) in a problem. Even worse, many of them involve multiple objectives (multiple inputs, multiple outputs). That means the objectives of the problems in question may be conflicting with each other. On the one hand, solving such problems can entertain multiple dimensionalities. If the factors involved in such decision-making process are all quantitative in nature, the best solution can be obtained by evaluating a multi-attribute utility function as follows [18]:

$$U_i\ (x_1; x_2; . . .; x_m) = k_1u_{i1}(x1) + K_2u_{i2}(x2) + . \ . k_mu_{im}(xm);\ \ i = 1; 2; . ..; n \qquad (3.1)$$

where $U_i(x1; x2; . . .; x_m)$ is the utility function of m attributes (i.e. inputs) of the ith alternative, x_i is attributed under consideration, k_j is weighing of j^{th} attribute such that summation of k_j is equal to 1 and u_{ij} is the effect of i^{th} alternative related to j^{th} attribute, that is, x_j.

Therefore, the solution to such problems is the feasible solution with the maximum or minimum value of the utility function. Subject to such setting, the quality of the solutions of such problems can be maintained relatively easily. The only concern would be to determine the scientific way to measure each input (i.e. x_i) and its effect (i.e. u_{ij}). Of course, finding the right balance between the set of weightings is also crucial as this may involve subjective judgment on the relative importance of one effect to the other effects.

On the other hand, many of the real-life problems are unfortunately not that easy to solve. This is mainly because most of them involve qualitative factors. That means they cannot be modeled mathematically as in Eq. (3.1), regardless of the aforementioned shortcomings. Therefore, how to quantify such qualitative variables is always a controversial topic, if not impossible, when solving such multiple-criteria decision-making (MCDM) problems. The controversy mainly comes from the subjective judgment of the qualitative factors, which always rely on experts' opinion, and is not consistently reliable. Such judgment inevitably affects the quality of the solution obtained. This is analogous in many cases to assign the weightings in Eq. (3.1).

Prof. Thomas L. Saaty developed a ground-breaking tool to handle such MCDM problems. This is called the analytic hierarchy process (AHP). The basic idea is to represent such

MCDM problems by a hierarchical structure with different criteria and their sub-criteria. Those criteria or sub-criteria can be qualitative or quantitative in nature. Then, pairwise comparisons among those criteria are performed so that the weightings of the criteria with respect to the problem can then be estimated. Although experts' judgment is also required in this procedure, at least there is a way to ensure that the judgment is consistent by examining the consistency ratio. In addition, this approach can be used to select the best alternative based on these weightings and their relative importance to each criterion.

3.6 Brief Review of AHP

Analytic Hierarchy Process (AHP) is one of Multi-Criteria decision-making method that was originally developed by Prof. Thomas L. Saaty. The Analytic Hierarchy Process (AHP) is a revolutionary breakthrough which empowers to relate intangibles to tangibles, the subjective to the objective, and to link both to their purposes. In short, it is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurements such as price, weight, etc., or from subjective opinions such as satisfaction feelings and preference. AHP allows some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigenvectors and the consistency index is derived from the principal Eigenvalue [4].

Since there are different factors that can affect decision involving multiple judging criteria, trade-offs can always be found between different factors. The analysis will usually involve multiple objectives or criteria. AHP is a useful approach for evaluating such complex multiple criteria alternatives. AHP is one of the widely used approaches to prioritize multiple factors. In order to evaluate or select an alternative, a design concept or a solution, weighted rating methods are generally used. It is a combinatorial decision analysis of quantitative and qualitative methods. The basic idea of AHP is to establish an orderly hierarchical system by analyzing elements of complex systems and their mutual relations. Proposed by Saaty, AHP has been employed to aid in many MCDM problems, particularly when qualitative criteria are involved. AHP is a useful approach for evaluating two or more competing alternatives along with multiple criteria. AHP requires a decision-maker to determine the relative importance of each criterion/factor by means of pairwise comparisons between the relevant criteria/factors included in the analysis. After the development of AHP, it has been employed to solve MCDM problems [4].

AHP analyses an MCDM problem by setting up a hierarchy of criteria and sub-criteria, which could be either quantitative or qualitative in nature. This can be done by introducing a pairwise comparison between those criteria, which are assessed by professionals or experts in the corresponding area.

3.6.1 Pair-Wise Comparison

The pairwise comparison is the measure of importance/preference of one attributes over another with respect to the objectives/attributes/sub-attributes.

If the number of attributes is n, the pairwise comparisons are required can be calculated by:

No. of pairwise comparison = n (n-1)/2.

3.6.2 Consistency index and consistency ratio

To check the consistency of the pairwise comparison matrix, consistency index (CI) and consistency ratio (CR) is calculated. If someone's qualitative judgment is as:

A > B, and B> C, then in case of consistency opinion A>C

Prof. Saaty proved that for consistent reciprocal matrix, the largest Eigenvalue is equal to the number of variables/attributes, or $\lambda_{max} = n$. Then he gave a measure of consistency, called Consistency Index as deviation or degree of consistency using the following formula.

$$CI = (\lambda_{max} - n) / (n-1) \tag{3.2}$$

For using the consistency index, Prof. Saaty proposed that we use this index by comparing it with the appropriate one. The appropriate Consistency index is called Random Consistency Index (RI). He randomly generated reciprocal matrix using his scale and get the random consistency index to see if it is 10% or less and finally gives a table for RI.

Table 3-2: Random Consistency Index (RI)

Matrix size (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

By using RI, We can calculate Consistency Ratio (CR), which is a comparison between Consistency Index and Random Consistency Index, or in formula

$$CR = CI/RI \tag{3.3}$$

If the value of CR is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

3.6.3 Formulation/Steps of AHP

The mathematical formulation of the AHP has been well presented by Saaty. The AHP provides a means of decomposing the problem into a hierarchy of sub-problems which can more easily be comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values and processed to rank each alternative on a numerical scale. The AHP uses hierarchical decision models and it has a sound mathematical basis. A model is a representation of a phenomenon. It can be manipulated the model, either physically if it is a physical model, or mathematically in the case of the hierarchical model, in an attempt to discover the important influences. The methodology of the AHP can be explained in the following steps [18]:

Step 1: The problem is decomposed into a hierarchy of goal, criteria, sub-criteria, and alternatives. This is the most creative and important part of decision-making. Structuring the decision problem as a hierarchy is fundamental to the process of the AHP. Hierarchy indicates a relationship between elements of one level with those of the level immediately below. This relationship percolates down to the lowest levels of the hierarchy and in this manner, every element is connected to every other one, at least in an indirect manner. A hierarchy is a more orderly form of a network. Saaty suggests that a useful way to structure the hierarchy is to work down from the goal as far as one can and then work up from the alternatives until the levels of the two processes are linked in such a way as to make comparisons possible. Figure 3.1 shows a generic hierarchic structure. This local concentration of the decision-maker on only part of the whole problem is a powerful feature of the AHP.

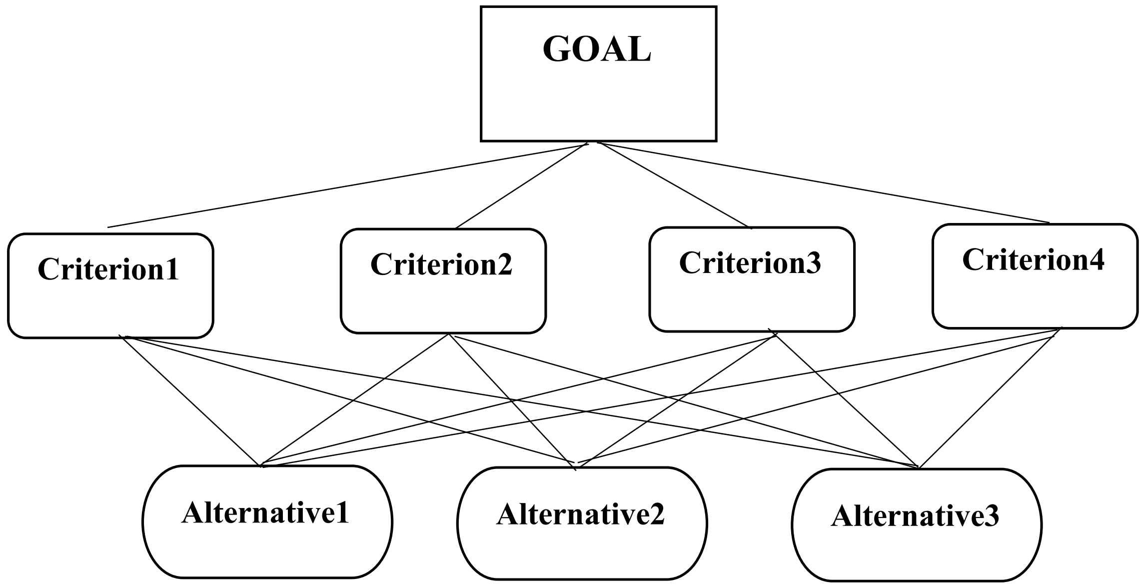


Figure 3.1: Generic hierarchic structure of AHP

Step 2: Data are collected from experts or decision-makers corresponding to the hierarchic structure, in the pairwise comparison of alternatives on a qualitative scale.

Step 3: The pair-wise comparisons of various criteria generated at step 2 are organized into a square matrix. The diagonal elements of the matrix are 1. The criterion in the *i*th row is better than criterion in the j^{th} column if the value of the element (i, j) is more than 1; otherwise, the criterion in the j^{th} column is better than that in the i^{th} row. The (j, i) element of the matrix is the reciprocal of the (i, j) element.

Step 4: The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalized eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives.

Step 5: The consistency of the matrix of order *n* is evaluated.

Step 6: The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global weight.

Step7: According to the Global weight the ranking of Alternatives can be determined.

In this thesis, AHP will be preferred in the prioritization of different 3D printing technologies since this method is the only one using a hierarchical structure among goal, attributes, and alternatives. Usage of pair-wise comparisons is another asset of this method that lets the generation of more precise information about the preferences of decision-makers. Moreover, since the decision-makers are usually unable to explicit about their preferences due to the fuzzy nature of the decision process, this method helps them providing an ability to give interval judgments instead of point judgments.

3.7 Financial Feasibility Study

Financial feasibility study is very important to analyze decisions. Through this study it is easy to take decision whether decision maker should or should not replace the traditional technology by new technology. For this part of this thesis I have followed the following steps:

Step 1: At first selected one core 3D printing related company in Bangladesh which have the diversified work experience on different types of industry.

Step 2: Collected the data for 3D printing works of following industries and sectors:

- New product development in Group of company
- Small batch production for SME
- Medical implant
- Architectural Model making
- Machine parts & spare parts making
- Cottage Industries
- Entertainment industry
- Agricultural Industry
- Educational & Toys Industries.

Step 3: Those different sectors 3D printing works financial feasibility study has been perform based on following criteria which has the direct impact on the costing. After that provided a comparison between traditional manufacturing processes based on those similar criteria. Selected criteria are the followings:

- Machine set up cost
- Labor Cost
- Material cost
- Travel/Transport cost
- Waste reduction
- Production Time
- Inventory cost/production on demand

Step 5: Calculation of Return on Investment (ROI) and Internal Rate of Return (IRR)

3.7.1 IRR & ROI Calculation

To measure the performance of an investment, Return on Investment (ROI) and Internal Rate of Return (IRR) are two popular metrics.

Return on investment—sometimes called the rate of return (ROR)—is the percentage increase or decrease in an investment over a set period. It is calculated by taking the difference between current, or expected, value and original value divided by the original value and multiplied by 100.

IRR is a metric that doesn't have any real formula. It means that no predetermined formula can be used to find out IRR. The value that IRR seeks is the rate of discount which makes the Net Present Value (NPV) of the sum of inflows equal to the initial net cash invested.

Companies use this metric for capital budgeting estimates and to assess the profitability of potential investments. Also, the firms calculate the IRR when undertaking expansion plans or setting the budget. The mechanism helps companies to decide the project in which the investment should be made. Simply put, IRR is the discount rate that makes the net present value of all the cash flows from a specific project as zero.

Formula:

In Case of ROI :[(Expected value – Original value)/Original value] x 100

$$\text{Return on Investment (ROI)} = \frac{\text{Profit}}{\text{Investment}} \text{ x } 100\%$$

$$\textbf{ROI} = \frac{\text{(Number of parts per year x cost savings per part x number of year)} - \text{(total investment machine life)}}{\text{(Total investment over machine life)}} \text{x100\%}$$

There is no direct algebraic expression in which we might plug some numbers and get the IRR.[67]

IRR is most commonly calculated using the hit-and-trial method, linear-interpolation formula or spreadsheets and financial calculators.

Since IRR is defined as the discount rate at which NPV = 0, we can write that:

NPV = 0; or PV of future cash flows − Initial Investment = 0; or

$$\left[\frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \ldots\right] - \text{Initial Investment} = 0$$

Where,

r is the internal rate of return;

CF_1 is the period one net cash inflow;

CF_2 is the period two net cash inflow,

CF_3 is the period three net cash inflow, and so on ...

But the problem is, we cannot isolate the variable **r** (=internal rate of return) on one side of the above equation. Even though we can use the linear-interpolation formula, the simplest method is to use hit and trial as described below:

1. STEP 1: Guess the value of r and calculate the NPV of the project at that value.
2. STEP 2: If NPV is close to zero then IRR is equal to r.
3. STEP 3: If NPV is greater than 0 then increase r and jump to step 5.
4. STEP 4: If NPV is smaller than 0 then decrease r and jump to step 5.
5. STEP 5: Recalculate NPV using the new value of r and go back to step 2.

Step 5: Based on this comparison between Additive Manufacturing and Traditional Manufacturing final recommendation provided on financial feasibility of 3D printing technology.

3.8 Expert's Personal Profile

To prepare the pair-wise comparison matrices for the main criteria and alternatives, opinion and questionnaire answer of 14 experts of the relevant additive manufacturing field are collected by purposive sampling method. Among 14 experts, 10 experts opinion has been considered for further analysis, here not considered for 4 due to incomplete response of questionnaire. The experts category, Education & experience level is shown in below table 3-3 (detail personal profile has given in appendix).

Table 3-3: The experts' category, Education & experience level

Work area	Education	Experience	No. of respondents
3D Printing Related Entrepreneur	Minimum Graduate Engineer	4 yrs minimum professional experience	3
University Teacher	Minimum related education & research	5 yrs minimum professional experience	2
Professional user	Minimum Graduate Engineer	5 yrs minimum professional experience	3
Researcher	Minimum Graduate Engineer	4 yrs research experience	2

3.8.1 Weightage assign for the Experts

In this study according to following attributes of individual expert weightage has been assigned:

- Ability to Machine Design
- Expertize on 3D Modelling
- Machine Assembly
- 3D Printing Application experience
- Additive manufacturing R&D experience
- Depth knowledge about all technology

- Customer service experience
- Relevant Education/Knowledge
- FabLab involvement
- Participation in open source community

Table 3-4: Weightage distribution chart based on the individual expert attributes

SL	Attributes	Scale	Expert1	Expert2	Expert3	Expert4	Expert5	Expert6	Expert7	Expert8	Expert9	Expert10
1	Machine Design	5	3				3					
2	3D Modelling	5	3						2			
3	Assembly	5	3				2					
4	Case studied Application experience	5	3				1					
5	R&D experience	5	3	3			2		3		3	
6	Depth knowledge about all technology	5	3	3	1	1	2	1	2	1	2	1
7	Customer service experience	5	3				1				1	
8	Relevent Education	5	3	3	3	3	3	3	3	3	3	3
9	Fablab involvement	5	3	3	2	2		2	2	2	2	2
10	Participation in open source community	5	3				1					
	Total Score	50	30	12	6	6	15	6	12	6	11	6
	ssigned score as per obtained scor		**30%**	**10%**	**5%**	**5%**	**15%**	**5%**	**10%**	**5%**	**10%**	**5%**

3.9 Technology Transfer through Triple Helix Model

This study analyzes innovation process involving three actors (industry, academia, and government) in Bangladesh. For successful implementation of 3D printing technology in Bangladesh it is very important to interactions among the major three actors. For this purpose triple helix model is one of the best model.

In identifying the roles and interactions between different actors in the triple helix perspective and identifying how the innovation ecosystem works with the government support, this study use interview like discussions with relevant professional of Academia, Government & Industry. Discussions conducted with Government related officials, University researcher, Fablab professionals & Additive Manufacturing company owner.

For this part of this thesis followed the following steps:

Step 1: Ask recommendation and possible contribution area from one of the government senior official of Bangladesh Industrial Technical Assistance Centre (BITAC) under Ministry of Industries, one of the senior official from ICT ministry and one 3D printing company entrepreneur.

Step 2: Ask recommendation and possible contribution area from one of the renowned and experienced entrepreneur of 3D Printing sectors.

Step 3: Ask recommendation and possible contribution area from one of the renowned and experienced academician who is related with the 3D Printing sector.

All of respondents will answer based on the following questions:

- Give your suggestion for Technology Transfer of 3D printing Technology in Bangladesh.
- How to use and integrate the strength of Educational Institutes, Government & Industry in the 3D Printing technology transfer process in Bangladesh?
- What's the major role of Educational Institutes in 3D printing technology transfer process in Bangladesh?
- What's the major role of Government in 3D printing technology transfer process in Bangladesh?
- What's the major role of 3D Printing Industry in 3D printing technology transfer process in Bangladesh?

After that developed a matrix of contributor and possible area of contribution for implementation and promote 3D printing technology in Bangladesh.

Step 4: Based on the literature review and collected data develop triple helix circle for showing the current activities, possible scope of collaboration and recommendation future improvement.

Step 5: Based on Schumpeterian trilogy of Technology Transfer will develop the TT process within the framework of Triple helix.

The Schumpeterian trilogy divided the technological change process into three distinct phases: [65]

- Invention: The technological change process including the conception of new ideas.

- Innovation: The innovation process that involves the development of new ideas into marketable products and processes. "The doing of new things or the doing of things that are already being done in a new way."
- Diffusion: The diffusion stage in which the new products and processes spread across the potential market.

Step 6: Define the Sub-actors for Triple Helix actors and their possible contribution area to develop matrix for the implementation of 3D printing technology in Bangladesh.

3.9.1 Contributor:

- **Academia**
  - University
  - School & College
- **Government**
  - Fablab
  - Ministry of Industry
  - ICT Ministry
  - Ministry of Education
- **Industry**
  - 3D Printing service provider
  - 3D Printing Machine Manufacturer
  - User Industry

3.8.2 Possible Area of Contribution

- Funding
- Human resource
- Training
- Incubation Center
- Application R&D
- Machine Manufacturing R&D
- Equipment’s
- Technology Transport Support
- Commercial
- Legal & Administrative Support
- Information Centre
- New product development
- Technology Awareness
- Education
- Innovation
- Market Development

Chapter 4

DATA ANALYSIS, RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter of this thesis, mathematical calculation of the pair-wise comparison matrices has been performed. To calculate the weight of different alternatives, used Excel for the mathematical operation of matrices and AHP online calculator for Pairwise comparison matrix for criteria with respect to objectives.

4.2 Result Calculation

The data analysis has been made using Microsoft Excel spread sheet and AHP online software. The matrices have diagonal of unity. The reversal triangles were made just reversing the corresponding component using equation 3.3. The pair wise comparison matrices are developed by expert opinion. The detailed calculation is shown in this chapter.

This research work, performs the appropriate 3D printing technology selection for manufacturing sector in Bangladesh. The 3D printing technology aims to shift the manufacturing of products from industry to home. It helps users to produce their product with the design, material choice and strength of their own choice and requirements. At present, there exist mainly ten types of polymer based 3D printing technologies that include. FDM Pallet based, FDM Filament based, Material Jetting, Binder Adhesive type, Photopolymer jetting, Laminated Object manufacturing DLP SLA, LCD SLA, and CLIP SLA.

MDCM has been used for a better decision making for the deployment of the specific 3D printing technology according to country's demands. The Multiple-criteria decision-making (MCDM) specifically evaluates several conflicting criteria for final decision making. MCDM organizes the complex problems like deployment of new products in a country efficiently by considering various critical criteria and makes better choices and judgements.

The AHP is a technique that has been deployed this research work and its analysis. It computes the relative weights of multiple significant criteria and has higher accuracy. It uses pairwise comparison matrices to estimate the relative weights of the factors involved in decision making process. The weights are determined by utilizing experiences from different experts. A special questionnaire is designed for the problem solving and the experts the significance of multiple items as compared to each other.

This research developed a questionnaire related to the deployment of 3D technologies in Bangladesh which was then handed over to ten different experts in the area. The experts provided their valuable insights with their experiences and developed a comparison matrix of different technologies that are used in 3D printing processes. In the following section we will present the comparison matrices of different technologies as evaluated by experts and the final results provided by each.

4.3 AHP Calculation of Experts Data

To present and analyse the expert data used the AHP online calculator for Pairwise comparison matrix for criteria with respect to objectives and to calculate the weight of different alternatives, used Excel for the mathematical operation of matrices as per AHP methodology with Satty scale.

We have taken data from 10 professional 3d printing related experts, among them highest weightage (30%) assigned for the expert 1 for his specific expertise in this sector. Here I provided the detail calculation only for the expert-1, for other experts only summarized calculation has been provided and summarized calculation mentioned accordingly.

4.3.1 Detail data analysis for expert 1

The matrix of pair wise comparisons denotes the intensities of the expert's preference between individual pairs of alternatives. Let's build a matrix for criteria's considering Expert-1 feedback in Table 4-1.

Table 4-1: Pairwise comparison matrix for criteria with respect to objectives (expert-1)

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consumption	Material variety	Production rate
Dimensional	1	1	1/2	2	3	1	1	1/4	1/2	2	2	3	2
Mechanical pro.	1	1	1/2	2	2	1	4	1/2	2	3	3	2	1
Manu cost	2	2	1	4	2	3	1	1	2	2	1	3	3
Build volume	1/2	1/2	1/4	1	1	2	1/3	1/2	1/3	1/3	1	1	1/3
Post-processing	1/3	1/2	1/2	1	1	1/2	1/2	1/3	1/2	1/3	1/3	1/2	1/2
Raw material	1	1	1/3	1/2	2	1	3	1/2	1	3	3	2	3
Technical know	1	1/4	1	3	2	1/3	1	1	1/2	2	2	3	2
Machine setup cost	4	2	1	2	3	2	1	1	3	1	3	2	2
Technology maintenance	2	1/2	1/2	3	2	1	2	1/3	1	3	2	1	2
Safety	1/2	1/3	1/2	3	3	1/3	1/2	1	1/3	1	2	2	3
Energy consumption	1/2	1/3	1	1	3	1/3	1/2	1/3	1/2	1/2	1	1	2
Material variety	1/3	1/2	1/3	1	2	1/2	1/3	1/2	1	1/2	1	1	1
Production rate	1/2	1	1/3	3	2	1/3	1/2	1/2	1/2	1/3	1/2	1	1

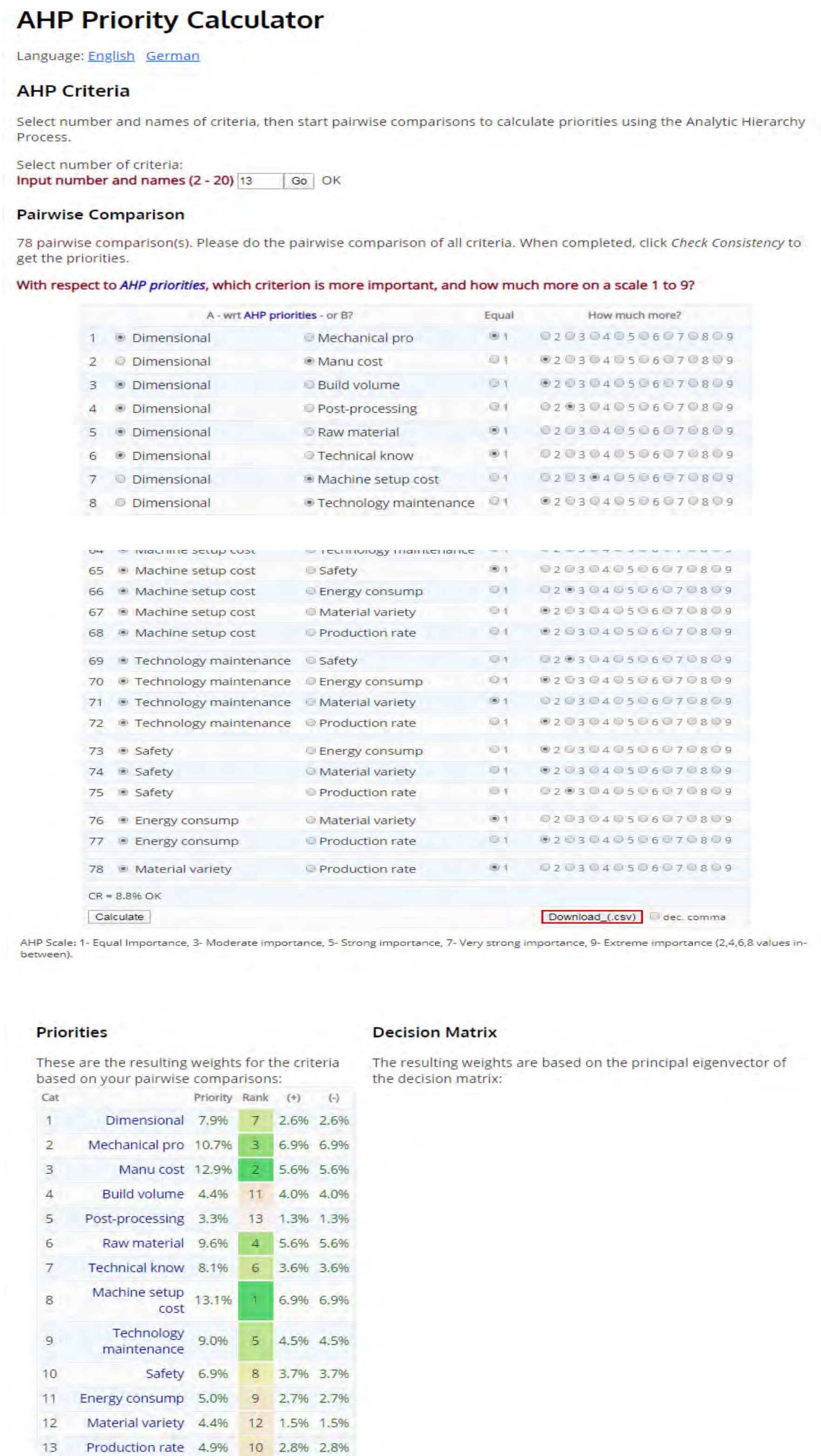
Using equations (2)-(5), Normalized value and priorities of pair wise comparison are calculated for above matrix for 3D printing technology selection. Table 4-2 presents normalized values and priorities.

Table 4-2: Priorities vector for pair wise comparison matrix of criteria

Criteria	**Priorities**
Dimensional Accuracy	0.079
Mechanical properties	0.107
Manufacturing cost	0.129
Build volume	0.044
Ease of Post-processing	0.033
Raw material availability	0.096
Technical know-how	0.081
Machine setup cost	0.131
Technology maintenance	0.09
Safety & Risk Level	0.069
Low Energy consumption	0.05
Material variety	0.044
Production rate	0.049

Matrix and calculation result presented in Table 4-1 and Table 4-2 respectively. These are accomplished using AHP-OC (AHP Online Calculator).

The web view of AHP-OC is conferred in Figure 4-1.



AHP Priority Calculator

Language: English German

AHP Criteria

Select number and names of criteria, then start pairwise comparisons to calculate priorities using the Analytic Hierarchy Process.

Select number of criteria:
Input number and names (2 - 20) 13 Go OK

Pairwise Comparison

78 pairwise comparison(s). Please do the pairwise comparison of all criteria. When completed, click *Check Consistency* to get the priorities.

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

	A - wrt AHP priorities - or B?		Equal	How much more?
1	Dimensional	Mechanical pro	1	2 3 4 5 6 7 8 9
2	Dimensional	Manu cost	1	2 3 4 5 6 7 8 9
3	Dimensional	Build volume	1	2 3 4 5 6 7 8 9
4	Dimensional	Post-processing	1	2 3 4 5 6 7 8 9
5	Dimensional	Raw material	1	2 3 4 5 6 7 8 9
6	Dimensional	Technical know	1	2 3 4 5 6 7 8 9
7	Dimensional	Machine setup cost	1	2 3 4 5 6 7 8 9
8	Dimensional	Technology maintenance	1	2 3 4 5 6 7 8 9
65	Machine setup cost	Safety	1	2 3 4 5 6 7 8 9
66	Machine setup cost	Energy consump	1	2 3 4 5 6 7 8 9
67	Machine setup cost	Material variety	1	2 3 4 5 6 7 8 9
68	Machine setup cost	Production rate	1	2 3 4 5 6 7 8 9
69	Technology maintenance	Safety	1	2 3 4 5 6 7 8 9
70	Technology maintenance	Energy consump	1	2 3 4 5 6 7 8 9
71	Technology maintenance	Material variety	1	2 3 4 5 6 7 8 9
72	Technology maintenance	Production rate	1	2 3 4 5 6 7 8 9
73	Safety	Energy consump	1	2 3 4 5 6 7 8 9
74	Safety	Material variety	1	2 3 4 5 6 7 8 9
75	Safety	Production rate	1	2 3 4 5 6 7 8 9
76	Energy consump	Material variety	1	2 3 4 5 6 7 8 9
77	Energy consump	Production rate	1	2 3 4 5 6 7 8 9
78	Material variety	Production rate	1	2 3 4 5 6 7 8 9

CR = 8.8% OK

Calculate Download (.csv) dec. comma

AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Dimensional	7.9%	7	2.6%	2.6%
2	Mechanical pro	10.7%	3	6.9%	6.9%
3	Manu cost	12.9%	2	5.6%	5.6%
4	Build volume	4.4%	11	4.0%	4.0%
5	Post-processing	3.3%	13	1.3%	1.3%
6	Raw material	9.6%	4	5.6%	5.6%
7	Technical know	8.1%	6	3.6%	3.6%
8	Machine setup cost	13.1%	1	6.9%	6.9%
9	Technology maintenance	9.0%	5	4.5%	4.5%
10	Safety	6.9%	8	3.7%	3.7%
11	Energy consump	5.0%	9	2.7%	2.7%
12	Material variety	4.4%	12	1.5%	1.5%
13	Production rate	4.9%	10	2.8%	2.8%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

Figure 4-1: Priorities calculation for criteria with respect to objectives using AHP-OS

Similarly, Priorities calculation and consistency ratio of alternatives with respect to criteria are given below in tables.

Table 4-3: Pairwise comparison matrix of alternatives with respect to criteria Dimensional Accuracy

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	0.14	0.50	0.11	0.17	3.00	0.33	0.33	1.00	0.14	1.00	9
DLP SLA	7.00	1.00	3.00	0.50	4.00	9.00	3.00	3.00	7.00	1.00	7.00	3
BAT	2.00	0.33	1.00	0.11	0.50	2.00	0.50	0.50	0.14	0.17	2.00	8
LCD SLA	9.00	2.00	9.00	1.00	5.00	9.00	4.00	4.00	9.00	2.00	9.00	1
SLS	6.00	0.25	2.00	0.20	1.00	8.00	0.50	0.50	5.00	0.13	6.00	6
LOM	0.33	0.11	0.50	0.11	0.13	1.00	0.20	0.20	1.00	0.11	0.33	10
MJ	3.00	0.33	2.00	0.25	2.00	5.00	1.00	1.00	2.00	0.50	3.00	4
PJ	3.00	0.33	2.00	0.25	2.00	5.00	1.00	1.00	2.00	0.50	3.00	4
FDM (pallet)	1.00	0.14	7.00	0.11	0.20	1.00	0.50	0.50	1.00	0.11	1.00	7
CLIP SLA	7.00	1.00	6.00	0.50	8.00	9.00	2.00	2.00	9.00	1.00	7.00	2

CI 0.04

Random 1.49

CR 0.03

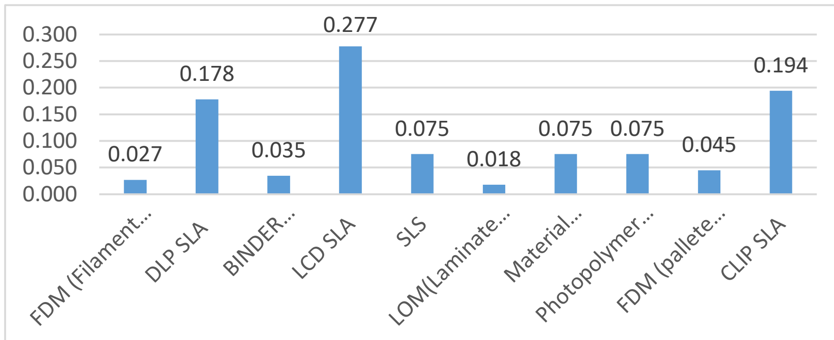


Figure 4-2: Pair-wise matrix priorities for criteria Dimensional criteria

Table 4-4: Pairwise comparison matrix of alternatives with respect to Mechanical Properties

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	2.00	3.00	3.00	3.00	4.00	0.25	0.33	0.50	2.00	10.0%	4
DLP SLA	0.50	1.00	2.00	1.00	3.00	2.00	0.25	0.33	2.00	1.00	7.8%	5
BAT	0.33	0.50	1.00	0.17	1.00	1.00	0.13	0.11	0.20	0.20	2.5%	10
LCD SLA	0.33	1.00	6.00	1.00	3.00	4.00	0.25	0.33	0.20	1.00	7.4%	6
SLS	0.33	0.33	1.00	0.33	1.00	1.00	0.25	0.11	0.20	0.33	2.8%	9
LOM	0.25	0.50	1.00	0.25	1.00	1.00	0.33	0.11	0.20	0.33	2.9%	8
MJ	4.00	4.00	8.00	4.00	4.00	3.00	1.00	0.50	2.00	3.00	19.8%	2
PJ	3.00	3.00	9.00	3.00	9.00	9.00	2.00	1.00	3.00	4.00	26.3%	1
FDM (pallet)	2.00	0.50	5.00	5.00	5.00	5.00	0.50	0.33	1.00	2.00	13.2%	3
CLIP SLA	0.50	1.00	5.00	1.00	3.00	3.00	0.33	0.25	0.50	1.00	7.2%	7

CI 0.026

Random 1.49

CR 0.02

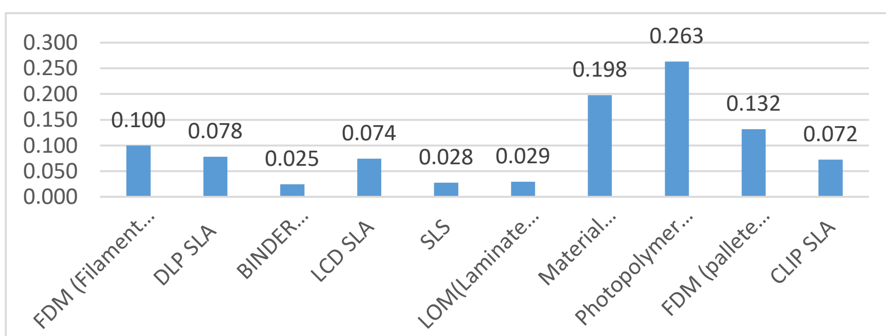


Figure 4-3: Pair-wise matrix & priorities for Mechanical Properties criteria

Table 4-5: Pairwise comparison matrix of alternatives with respect to Manufacturing cost

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	3.00	6.00	2.00	3.00	3.00	4.00	4.00	0.50	2.00	17.2%	2
DLP SLA	0.33	1.00	2.00	0.50	2.00	2.00	5.00	3.00	0.25	2.00	9.4%	5
BAT	0.17	0.50	1.00	0.20	2.00	2.00	6.00	6.00	0.14	0.50	7.5%	6
LCD SLA	0.50	2.00	5.00	1.00	3.00	3.00	3.00	4.00	0.25	2.00	13.2%	3
SLS	0.33	0.50	0.50	0.33	1.00	1.00	4.00	4.00	0.50	0.50	6.5%	7
LOM	0.33	0.50	0.50	0.33	1.00	1.00	2.00	4.00	0.25	0.50	5.3%	8
MJ	0.25	0.20	0.17	0.33	0.25	0.50	1.00	1.00	0.33	0.11	2.9%	9
PJ	0.25	0.33	0.17	0.25	0.25	0.25	1.00	1.00	0.33	0.11	2.8%	10
FDM (pallet)	2.00	4.00	7.00	4.00	2.00	4.00	3.00	3.00	1.00	3.00	23.9%	1
CLIP SLA	0.50	0.50	2.00	0.50	2.00	2.00	9.00	9.00	0.33	1.00	11.3%	4

CI 0.071

RI 1.49

CR 0.05

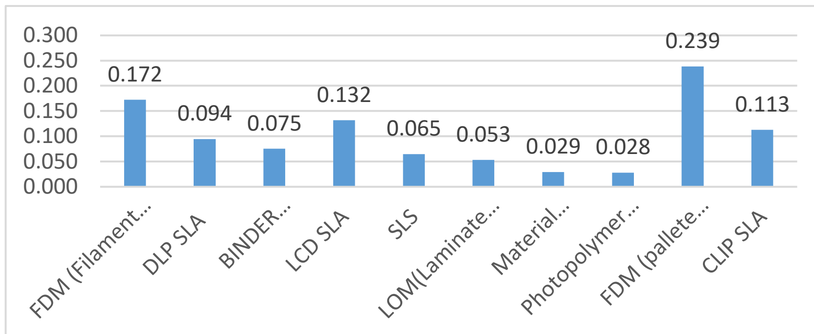


Figure 4-4: Pair-wise matrix & priorities for Manufacturing cost criteria

Table 4-6: Pairwise comparison matrix of alternatives with respect to Build Volume

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	2.00	5.00	5.00	1.00	5.00	3.00	2.00	1.00	4.00	19.5%	1
DLP SLA	0.50	1.00	3.00	5.00	2.00	2.00	2.00	2.00	0.50	0.50	11.9%	3
BAT	0.20	0.33	1.00	5.00	1.00	1.00	4.00	1.00	0.33	2.00	8.5%	5
LCD SLA	0.20	0.20	0.20	1.00	0.25	0.33	0.33	0.14	0.14	0.50	2.3%	10
SLS	1.00	0.50	1.00	4.00	1.00	2.00	2.00	3.00	0.50	2.00	11.5%	4
LOM	0.20	0.50	1.00	3.00	0.50	1.00	0.50	2.00	0.33	0.50	5.9%	8
MJ	0.33	0.50	0.25	3.00	0.50	2.00	1.00	0.33	0.17	0.33	4.9%	9
PJ	0.50	0.50	1.00	7.00	0.33	0.50	3.00	1.00	0.50	1.00	8.0%	7
FDM (pallet)	1.00	2.00	3.00	7.00	2.00	3.00	6.00	2.00	1.00	3.00	19.3%	2
CLIP SLA	0.25	2.00	0.50	2.00	0.50	2.00	3.00	1.00	0.33	1.00	8.2%	6

CI 0.06

RI 1.49

CR 0.04

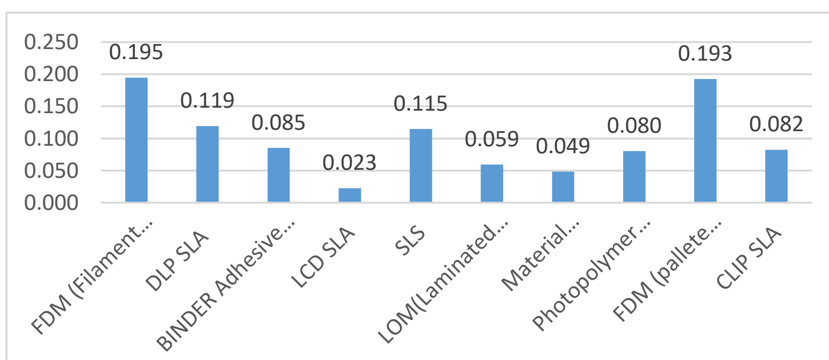


Figure 4-5: Pair-wise matrix & priorities for Build Volume criteria

Table 4-7: Pairwise comparison matrix of alternatives with respect to Ease of Post-processing

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weig ht	Rank
FDM (Filament)	1.00	4.00	4.00	2.00	4.00	5.00	0.50	0.50	2.00	4.00	15.2%	3
DLP SLA	0.25	1.00	3.00	0.50	3.00	4.00	0.20	0.50	1.00	1.00	7.1%	6
BAT	0.25	0.33	1.00	0.14	0.50	1.00	0.33	0.25	0.14	0.50	3.0%	10
LCD SLA	0.50	2.00	7.14	1.00	5.00	9.00	0.33	0.33	1.00	2.00	12.2%	4
SLS	0.25	0.33	2.00	0.20	1.00	2.00	0.14	0.14	0.20	0.33	3.1%	8
LOM	0.20	0.25	1.00	0.11	0.50	1.00	0.33	0.25	0.50	0.25	3.1%	9
MJ	2.00	5.00	3.00	3.00	7.00	3.00	1.00	1.00	3.00	2.00	19.9%	2
PJ	2.00	2.00	4.00	3.00	7.00	4.00	1.00	1.00	3.00	5.00	20.4%	1
FDM (pallet)	0.50	1.00	7.00	1.00	5.00	2.00	0.33	0.33	1.00	2.00	9.5%	5
CLIP SLA	0.25	1.00	2.00	0.50	3.00	4.00	0.50	0.20	0.50	1.00	6.4%	7

CI 0.039

RI 1.49

CR 0.03

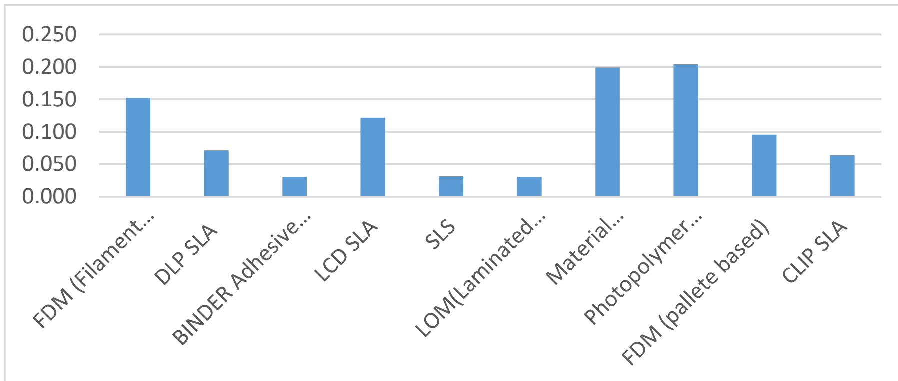


Figure 4-6: Pair-wise matrix & priorities for Ease of Post-processing criteria

Table 4-8: Pairwise comparison matrix of alternatives with respect to Raw Material Availability

Alternatives	FDM (Filament)	DLP SLA	BA T	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	2.00	4.00	2.00	5.00	4.00	3.00	2.00	1.00	1.00	15.4%	2
DLP SLA	0.50	1.00	7.00	1.00	7.00	4.00	2.00	7.00	0.25	1.00	13.9%	4
BAT	0.25	0.14	1.00	0.33	1.00	1.00	1.00	1.00	0.33	0.25	3.7%	10
LCD SLA	0.50	1.00	3.00	1.00	6.00	4.00	3.00	7.00	0.25	1.00	12.5%	5
SLS	0.20	0.14	1.00	0.17	1.00	2.00	4.00	4.00	0.33	0.25	6.0%	6
LOM	0.25	0.25	1.00	0.25	0.50	1.00	0.50	1.00	0.50	0.25	3.7%	9
MJ	0.33	0.50	1.00	0.33	0.25	2.00	1.00	1.00	0.50	0.14	4.6%	7
PJ	0.50	0.14	1.00	0.14	0.25	1.00	1.00	1.00	0.50	0.14	3.9%	8
FDM (pallet)	1.00	4.00	3.00	4.00	3.00	2.00	2.00	2.00	1.00	4.00	21.7%	1
CLIP SLA	1.00	1.00	4.00	1.00	4.00	4.00	7.00	7.00	0.25	1.00	14.7%	3

CI 0.075

RI 1.41

CR 0.05

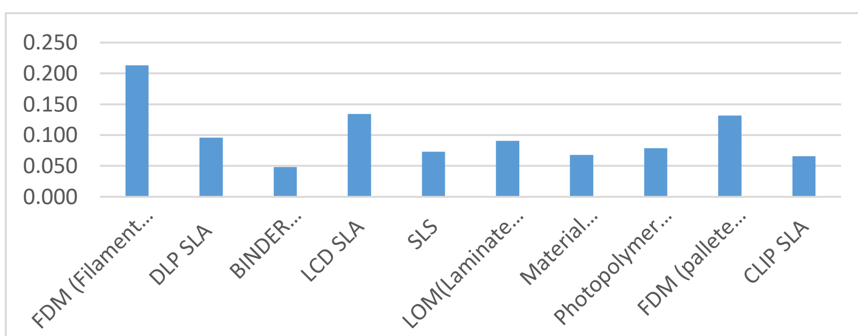


Figure 4-7: Pair-wise matrix & priorities for Raw Material Availability criteria

Table 4-9: Pairwise comparison matrix of alternatives with respect to Technical Know-how

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	1.00	0.50	3.00	1.00	2.00	0.33	0.50	0.50	1.00	9.8%	5
DLP SLA	1.00	1.00	1.00	2.00	0.33	3.00	0.50	0.25	0.90	1.00	7.0%	8
BAT	2.00	1.00	1.00	2.00	0.50	3.00	0.50	1.00	0.30	2.00	8.5%	7
LCD SLA	0.33	0.50	0.50	1.00	0.50	1.00	0.25	0.50	0.30	0.33	4.2%	10
SLS	1.00	3.00	2.00	2.00	1.00	3.00	1.00	1.00	0.70	1.00	12.3%	4
LOM	0.50	0.33	0.33	1.00	0.33	1.00	0.50	0.33	0.50	0.50	4.5%	9
MJ	3.00	2.00	2.00	4.00	1.00	2.00	1.00	2.00	0.33	3.00	13.9%	3
PJ	2.00	4.00	1.00	2.00	1.00	3.00	0.50	1.00	3.00	2.00	15.2%	2
FDM (pallet)	2.00	1.11	3.33	3.33	1.43	2.00	3.00	0.33	1.00	2.00	15.5%	1
CLIP SLA	0.25	4.00	2.00	2.00	0.50	1.00	1.00	0.50	0.50	0.25	9.1%	6

CI 0.103

RI 1.49

CR 0.07

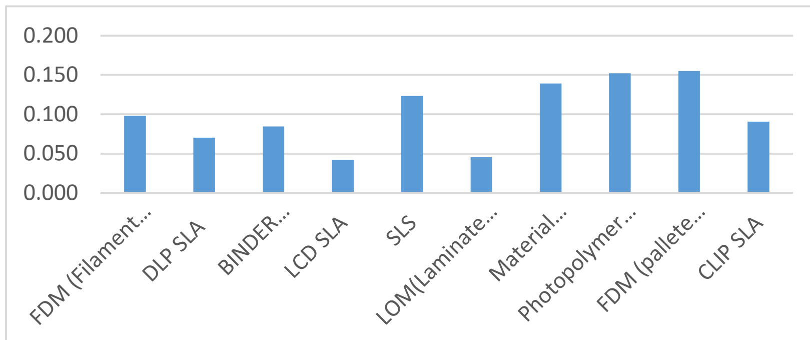


Figure 4-8: Pair-wise matrix & priorities for Technical Know-how criteria

Table 4-10: Pairwise comparison matrix of alternatives with respect to Machine set-up cost

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	3.00	3.00	1.00	5.00	5.00	4.00	3.00	1.00	4.00	19.9%	2
DLP SLA	0.33	1.00	1.00	0.50	1.00	1.00	3.00	6.00	0.50	2.00	8.6%	6
BAT	0.33	1.00	1.00	0.20	1.00	1.00	6.00	6.00	0.50	7.00	10.5%	4
LCD SLA	1.00	2.00	5.00	1.00	2.00	5.00	2.00	4.00	6.00	5.00	22.6%	1
SLS	0.20	1.00	1.00	0.50	1.00	1.00	4.00	4.00	0.50	5.00	8.9%	5
LOM	0.20	1.00	1.00	0.20	1.00	1.00	3.00	4.00	0.50	5.00	7.9%	7
MJ	0.25	0.33	0.17	0.50	0.25	0.33	1.00	1.00	0.33	2.00	3.9%	8
PJ	0.33	0.17	0.17	0.25	0.25	0.25	1.00	1.00	0.50	1.00	3.2%	9
FDM (pallet)	1.00	2.00	2.00	0.17	2.00	2.00	3.00	2.00	1.00	3.00	11.6%	3
CLIP SLA	0.25	0.50	0.14	0.20	0.20	0.20	0.50	1.00	0.33	1.00	2.8%	10

CI 0.106

RI 1.49

CR 0.07

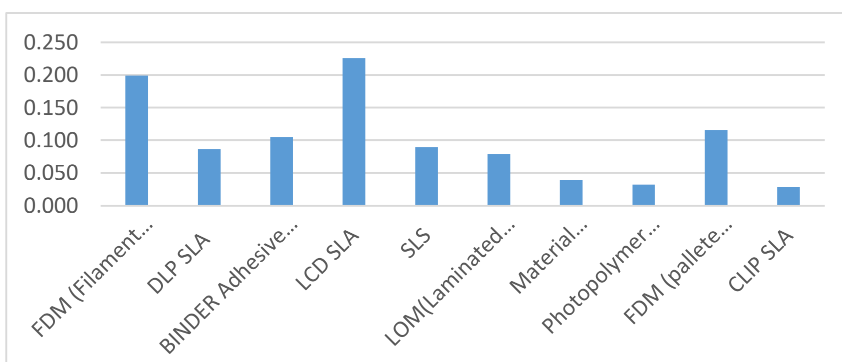


Figure 4-9: Pair-wise matrix & priorities for Machine set-up cost criteria

Table 4-11: Pairwise comparison matrix of alternatives with respect to Technology Maintenance

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	2.00	4.00	3.00	3.00	4.00	0.25	0.33	0.50	2.00	10.5%	4
DLP SLA	0.50	1.00	3.00	1.00	2.00	9.00	0.25	0.33	0.20	1.00	7.9%	6
BAT	0.25	0.33	1.00	0.33	1.00	1.00	0.13	0.50	0.33	0.20	3.5%	9
LCD SLA	0.33	1.00	3.00	1.00	2.00	5.00	0.25	0.33	0.20	1.00	6.7%	7
SLS	0.33	0.50	1.00	0.50	1.00	1.00	0.14	0.25	0.50	0.33	3.5%	8
LOM	0.25	0.11	1.00	0.20	1.00	1.00	0.14	0.33	0.20	0.33	2.9%	10
MJ	4.00	4.00	8.00	4.00	7.00	7.00	1.00	0.50	2.00	2.00	21.8%	1
PJ	3.00	3.00	2.00	3.00	4.00	3.00	2.00	1.00	3.00	2.00	20.0%	2
FDM (pallet)	2.00	5.00	3.00	5.00	2.00	5.00	0.50	0.33	1.00	2.00	14.7%	3
CLIP SLA	0.50	1.00	5.00	1.00	3.00	3.00	0.50	0.50	0.50	1.00	8.6%	5

CI 0.111

RI 1.49

CR 0.07

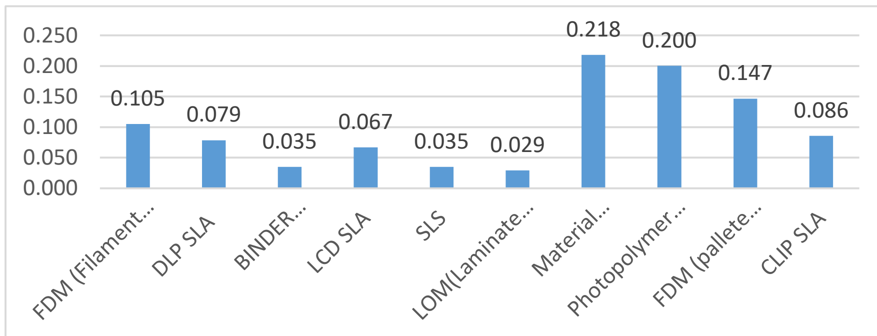


Figure 4-10: Pair-wise matrix & priorities for Technology Maintenance

Table 4-12: Pairwise comparison matrix of alternatives with respect to Safety & Risk Level

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	5.00	1.00	1.00	3.00	5.00	2.00	3.00	4.00	1.00	19.3%	2
DLP SLA	0.20	1.00	1.00	0.20	1.00	1.00	6.00	6.00	0.50	0.20	9.3%	5
BAT	1.00	1.00	1.00	0.50	2.00	2.00	6.00	6.00	2.00	1.00	13.3%	3
LCD SLA	1.00	5.00	2.00	1.00	5.00	3.00	3.00	2.00	4.00	1.00	20.4%	1
SLS	0.33	1.00	0.50	0.20	1.00	1.00	4.00	4.00	0.50	0.33	7.8%	7
LOM	0.20	1.00	0.50	0.33	1.00	1.00	4.00	4.00	0.50	0.20	7.8%	6
MJ	0.50	0.17	0.17	0.33	0.25	0.25	1.00	1.00	0.11	0.50	3.3%	9
PJ	0.33	0.17	0.17	0.50	0.25	0.25	1.00	1.00	0.11	0.33	3.6%	8
FDM (pallet)	0.25	2.00	0.50	0.25	2.00	2.00	9.00	9.00	1.00	0.25	12.1%	4
CLIP SLA	0.25	0.20	0.33	0.33	0.20	0.20	1.00	0.50	0.33	0.25	3.0%	10

CI 0.105

RI 1.49

CR 0.07

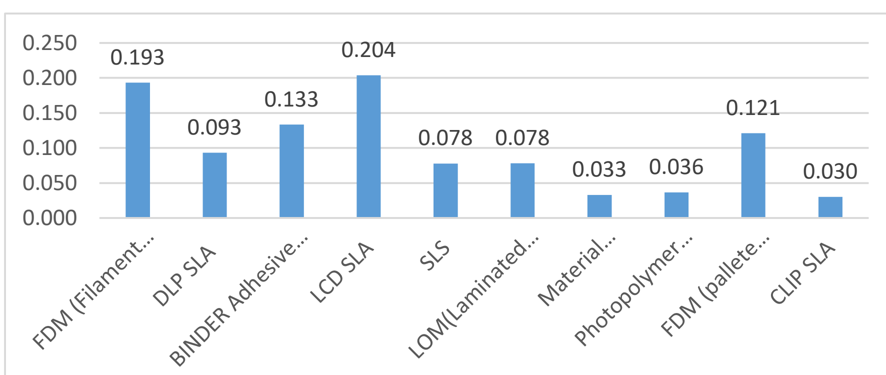


Figure 4-11: Pair-wise matrix & priorities for Safety & Risk Level criteria

Table 4-13: Pairwise comparison matrix of alternatives with respect to Low Energy Consumption

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	4.00	5.00	0.20	4.00	2.00	5.00	2.00	3.00	5.00	18.5%	2
DLP SLA	0.25	1.00	3.00	0.50	2.00	3.00	3.00	3.00	5.00	3.00	13.2%	3
BAT	0.20	0.33	1.00	0.20	3.00	1.00	1.00	1.00	3.00	3.00	6.9%	6
LCD SLA	5.00	2.00	5.00	1.00	4.00	7.00	5.00	3.00	5.00	5.00	27.4%	1
SLS	0.25	0.50	0.33	0.25	1.00	2.00	0.33	0.33	4.00	0.80	5.2%	9
LOM	0.50	0.33	1.00	0.14	0.50	1.00	3.00	3.00	3.00	0.50	7.3%	5
MJ	0.20	0.33	1.00	0.20	3.00	0.33	1.00	1.00	3.00	3.00	6.6%	7
PJ	0.50	0.33	1.00	0.33	3.00	0.33	1.00	1.00	3.00	3.00	7.3%	4
FDM (pallet)	0.33	0.20	0.33	0.20	0.25	0.33	0.33	0.33	1.00	0.20	2.5%	10
CLIP SLA	0.20	0.33	0.33	0.20	1.25	2.00	0.33	0.33	5.00	1.00	5.2%	8

CI 0.053

RI 1.49

CR 0.035

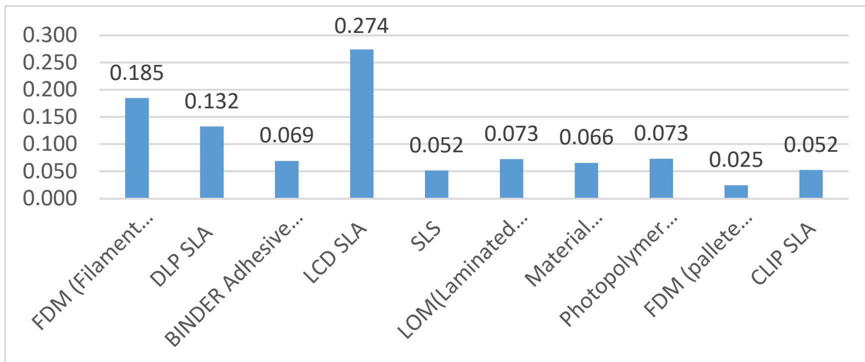


Figure 4-12: Pair-wise matrix & priorities for Low Energy Consumption

Table 4-14: Pairwise comparison matrix of alternatives with respect to Material Variety

Alternatives	FDM (Filament)	DLP SLA	BA T	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	0.50	2.00	0.50	5.00	3.00	0.25	0.25	2.00	0.33	7.0%	7
DLP SLA	2.00	1.00	3.00	1.00	5.00	4.00	0.25	0.25	2.00	0.25	8.7%	5
BAT	0.50	0.33	1.00	0.11	1.00	4.00	0.25	0.20	0.20	0.20	4.0%	9
LCD SLA	2.00	1.00	9.00	1.00	3.00	2.00	0.25	0.25	2.00	0.25	9.0%	4
SLS	0.20	0.20	1.00	0.33	1.00	3.00	0.25	0.33	0.20	0.20	3.8%	10
LOM	0.33	0.25	0.25	0.50	0.33	1.00	0.33	0.50	0.33	0.50	4.0%	8
MJ	4.00	4.00	4.00	4.00	4.00	3.00	1.00	1.00	2.00	0.50	16.5%	3
PJ	4.00	4.00	5.00	4.00	3.00	2.00	1.00	1.00	3.00	1.00	17.7%	2
FDM (pallet)	0.50	0.50	5.00	0.50	5.00	3.00	0.50	0.33	1.00	0.11	7.2%	6
CLIP SLA	3.00	4.00	5.00	4.00	5.00	2.00	2.00	1.00	9.00	1.00	22.1%	1

CI 0.077

RI 1.49

CR 0.051

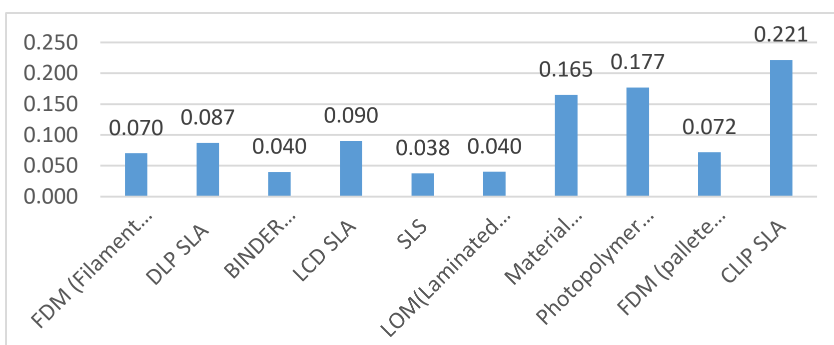


Figure 4-13: Pair-wise matrix & priorities for Material Variety criteria

Table 4-15: Pairwise comparison matrix of alternatives with respect to Production Rate

Alternatives	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	MJ	PJ	FDM (pallet)	CLIP SLA	Weight	Rank
FDM (Filament)	1.00	0.50	4.00	0.50	5.00	3.00	0.25	0.33	2.00	0.20	7.6%	6
DLP SLA	2.00	1.00	5.00	1.00	3.00	3.00	0.25	0.25	2.00	0.25	8.4%	5
BAT	0.25	0.20	1.00	0.25	1.00	1.00	0.20	0.25	0.50	0.13	2.7%	10
LCD SLA	2.00	1.00	4.00	1.00	6.00	3.00	0.25	0.25	2.00	0.25	9.1%	4
SLS	0.20	0.33	1.00	0.17	1.00	3.00	0.33	0.50	0.20	0.25	4.2%	8
LOM	0.33	0.33	1.00	0.33	0.33	1.00	0.20	0.33	0.20	0.20	2.9%	9
MJ	4.00	4.00	5.00	4.00	3.00	5.00	1.00	1.00	2.00	0.50	17.1%	2
PJ	3.00	4.00	4.00	4.00	2.00	3.00	1.00	1.00	3.00	0.50	15.8%	3
FDM (pallet)	0.50	0.50	2.00	0.50	5.00	5.00	0.50	0.33	1.00	0.20	7.2%	7
CLIP SLA	5.00	4.00	8.00	4.00	4.00	5.00	2.00	2.00	5.00	1.00	25.2%	1

CI 0.12

RI 1.49

CR 0.08

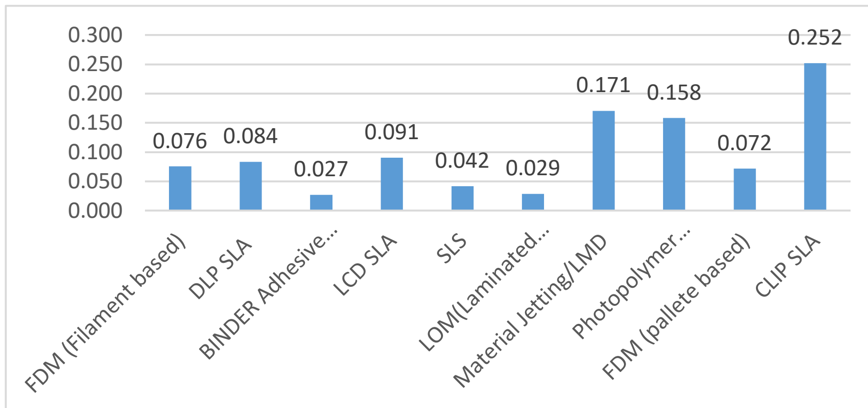


Figure 4-14: Pair-wise matrix & priorities for Production Rate criteria

A summarized comparison of the technology deployment review is shown in Table 4-16.

Table 4-16: Weightages of the various selection criteria of different 3D printing technologies based on expert 1 review.

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.079	0.107	0.129	0.044	0.033	0.096	0.081	0.131	0.09	0.069	0.05	0.044	0.049		
FDM (Filament)	0.027	0.1	0.172	0.126	0.152	0.154	0.098	0.199	0.105	0.193	0.185	0.07	0.076	0.133	3
DLP SLA	0.178	0.078	0.094	0.126	0.071	0.139	0.070	0.086	0.079	0.093	0.132	0.087	0.084	0.101	7
BINDER Adhesive	0.035	0.025	0.075	0.108	0.03	0.037	0.085	0.105	0.035	0.133	0.069	0.04	0.027	0.064	9
LCD SLA	0.277	0.074	0.132	0.022	0.122	0.125	0.042	0.226	0.067	0.204	0.274	0.09	0.091	0.139	2
SLS	0.075	0.028	0.065	0.114	0.031	0.06	0.123	0.089	0.035	0.078	0.052	0.038	0.042	0.066	8
LOM	0.018	0.029	0.053	0.065	0.031	0.037	0.045	0.079	0.029	0.078	0.073	0.04	0.029	0.048	10
Material Jetting	0.075	0.198	0.029	0.048	0.199	0.046	0.139	0.039	0.218	0.033	0.066	0.165	0.171	0.101	6
PJ	0.075	0.263	0.028	0.086	0.204	0.039	0.152	0.032	0.2	0.036	0.073	0.177	0.158	0.108	4
FDM (pallete based)	0.045	0.132	0.239	0.219	0.095	0.217	0.155	0.116	0.147	0.121	0.025	0.072	0.072	0.139	1
CLIP SLA	0.194	0.072	0.113	0.086	0.064	0.147	0.091	0.028	0.086	0.03	0.052	0.221	0.252	0.103	5

The review from expert 1 as given by Table 4-16 suggests that the FDM Pallet based & LCD SLA 3D printing technology outperforms all of the other options. This technology is suggested to be the best in terms of manufacturing cost, initial setup cost, Technology maintenance, technical know-how and the energy consumption cost. It also gives good performance in build volume. Whereas this technology is does not perform very well in case dimensions, mechanical properties and post processing are the priority deployment criteria.

In this study, the responds and data from expert-1 given highest emphasis due to this expert high level experience, knowledge & skill which has been mention in the table 4-26. According to his answered survey questionnaire we can considered the most appropriate 3d printing technology option is the FDM technology , as well as also LCD SLA very good prospect to deployment but it is ensure the RM availability , Maintenance & training for Technical know-how.

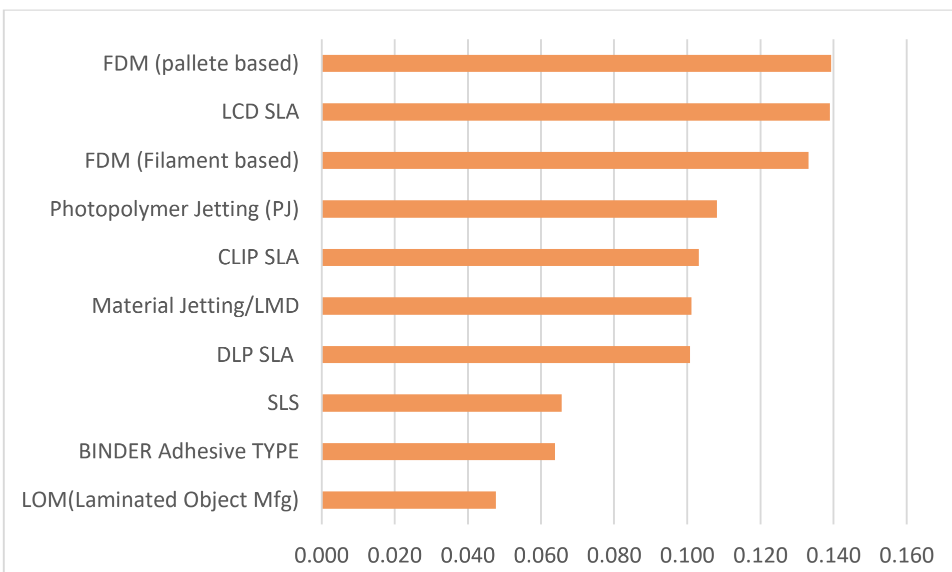


Figure 4-15: The ranking of technologies as estimated by review from expert 1

4.3.2 Analysis Summary of other experts' data:

Similar data analysis has been conducted by AHP-OS tool and excel based mathematical calculation done for the remaining nine experts. Summarized result presented in following tables and figures for the priorities of Criteria and Alternatives for the appropriate 3D Printing Technology selection.

From all the experts' calculation and analysis we can see that most of expert has the similarities in opinion based for FDM technology. Most of the experts preferred the FDM technology for Bangladesh. But there is some contraction among them to selection of FDM pallet based or FDM Filament. Both are much closed with each other in respect to their calculated weightage.

In upcoming tables and figures provided the summary of analysed data & their graphical presentation of nine experts. Detail calculation given to Appendix –C.

Table 4-17: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 2

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.127	0.114	0.106	0.047	0.032	0.095	0.094	0.106	0.073	0.052	0.046	0.046	0.061		
PJ	0.08	0.13	0.07	0.09	0.13	0.07	0.07	0.07	0.06	0.10	0.06	0.06	0.07	0.08	10
BINDER Adhesive	0.09	0.17	0.04	0.11	0.09	0.07	0.04	0.08	0.05	0.09	0.07	0.20	0.12	0.09	5
Material Jetting	0.06	0.14	0.09	0.05	0.13	0.07	0.09	0.11	0.03	0.11	0.06	0.08	0.11	0.09	9
LOM	0.09	0.06	0.08	0.07	0.06	0.09	0.08	0.06	0.09	0.15	0.16	0.09	0.15	0.09	6
CLIP SLA	0.09	0.11	0.07	0.09	0.09	0.08	0.06	0.09	0.11	0.07	0.18	0.09	0.07	0.09	7
LCD SLA	0.05	0.06	0.12	0.02	0.10	0.10	0.12	0.12	0.12	0.05	0.13	0.05	0.08	0.09	8
SLS	0.13	0.09	0.10	0.11	0.15	0.07	0.10	0.09	0.10	0.07	0.09	0.13	0.06	0.10	4
DLP SLA	0.11	0.08	0.10	0.13	0.08	0.15	0.10	0.06	0.14	0.16	0.07	0.07	0.07	0.10	3
FDM (Filament)	0.12	0.06	0.18	0.13	0.06	0.15	0.18	0.15	0.11	0.11	0.13	0.13	0.11	0.13	2
FDM (pallete based)	0.20	0.10	0.16	0.22	0.11	0.15	0.16	0.17	0.19	0.09	0.05	0.11	0.17	0.15	1

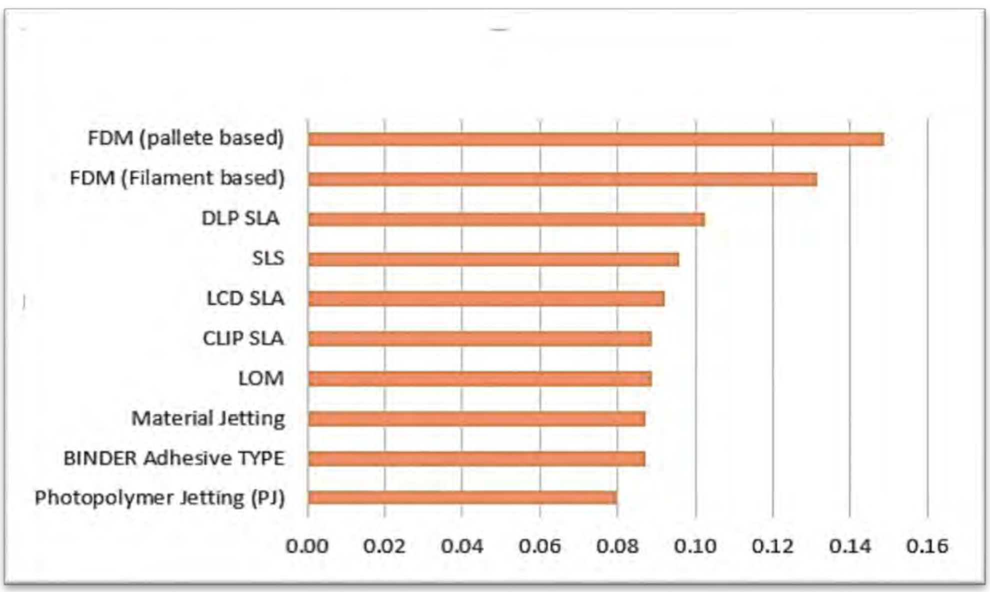


Figure 4-16: The ranking of technologies as estimated by review from expert -2

Table 4-18: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 3

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.06	0.128	0.14	0.035	0.044	0.107	0.071	0.097	0.09	0.06	0.052	0.056	0.061		
FDM (Filament)	0.095	0.050	0.172	0.095	0.094	0.116	0.198	0.176	0.143	0.129	0.175	0.094	0.070	0.126	2
DLP SLA	0.122	0.085	0.103	0.127	0.102	0.151	0.114	0.054	0.121	0.170	0.103	0.078	0.090	0.107	3
BINDER Adhesive	0.093	0.136	0.057	0.130	0.077	0.050	0.053	0.074	0.073	0.055	0.054	0.130	0.127	0.083	8
LCD SLA	0.042	0.054	0.104	0.050	0.049	0.130	0.106	0.127	0.177	0.145	0.115	0.035	0.074	0.099	5
SLS	0.155	0.172	0.087	0.126	0.117	0.064	0.085	0.107	0.099	0.066	0.079	0.149	0.067	0.106	4
LOM	0.073	0.056	0.077	0.081	0.042	0.080	0.072	0.057	0.058	0.070	0.101	0.085	0.167	0.076	10
Material Jetting	0.082	0.118	0.094	0.081	0.127	0.070	0.091	0.088	0.068	0.097	0.073	0.089	0.150	0.094	7
PJ	0.105	0.101	0.049	0.064	0.161	0.076	0.034	0.083	0.069	0.111	0.072	0.070	0.042	0.077	9
FDM (pallete based)	0.133	0.141	0.167	0.162	0.159	0.160	0.162	0.156	0.098	0.087	0.050	0.125	0.118	0.137	1
CLIP SLA	0.099	0.088	0.089	0.084	0.073	0.102	0.085	0.077	0.093	0.071	0.176	0.145	0.095	0.096	6

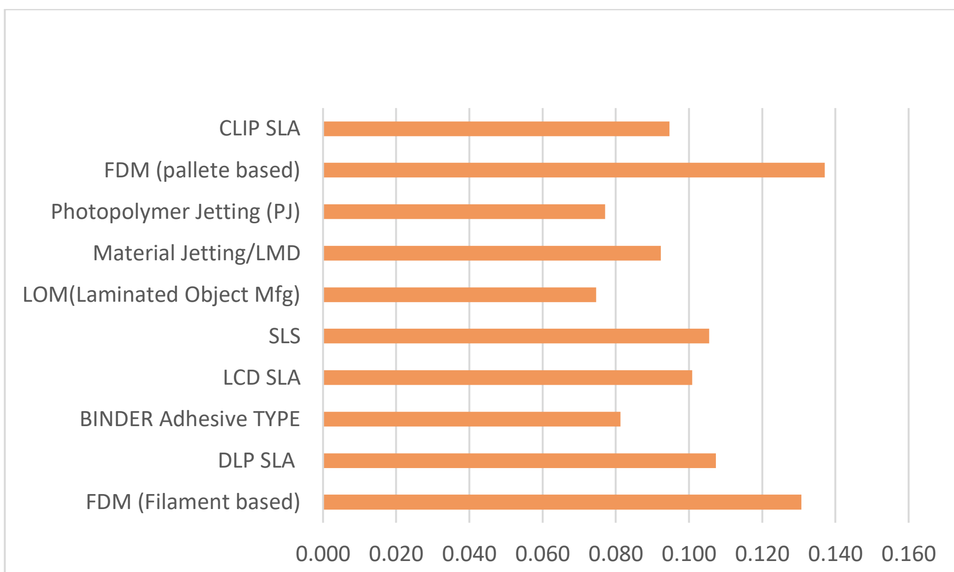


Figure 4-17: The ranking of technologies as estimated by review from expert 3

Table 4-19: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 4

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.128	0.129	0.112	0.031	0.039	0.087	0.103	0.106	0.063	0.066	0.035	0.044	0.056		
LOM	0.063	0.057	0.070	0.086	0.045	0.078	0.055	0.044	0.077	0.093	0.105	0.088	0.115	0.070	10
PJ	0.117	0.079	0.059	0.085	0.151	0.078	0.062	0.081	0.061	0.157	0.061	0.044	0.064	0.084	9
BINDER Adhesive	0.128	0.150	0.050	0.111	0.092	0.051	0.047	0.078	0.050	0.068	0.059	0.163	0.120	0.089	7
CLIP SLA	0.084	0.097	0.075	0.114	0.080	0.074	0.083	0.082	0.086	0.072	0.150	0.064	0.100	0.086	8
DLP SLA	0.114	0.058	0.116	0.113	0.075	0.097	0.106	0.082	0.104	0.101	0.124	0.064	0.096	0.095	5
SLS	0.106	0.117	0.110	0.113	0.121	0.082	0.089	0.098	0.102	0.071	0.081	0.170	0.046	0.100	4
LCD SLA	0.041	0.059	0.103	0.049	0.044	0.131	0.125	0.162	0.130	0.050	0.187	0.055	0.073	0.094	6
Material Jetting	0.104	0.189	0.084	0.077	0.143	0.066	0.081	0.110	0.067	0.086	0.060	0.111	0.172	0.107	3
FDM (Filamen)	0.096	0.067	0.176	0.096	0.111	0.174	0.182	0.140	0.164	0.180	0.108	0.153	0.078	0.134	2
FDM (pallete)	0.148	0.127	0.157	0.156	0.139	0.168	0.171	0.123	0.159	0.122	0.066	0.088	0.137	0.140	1

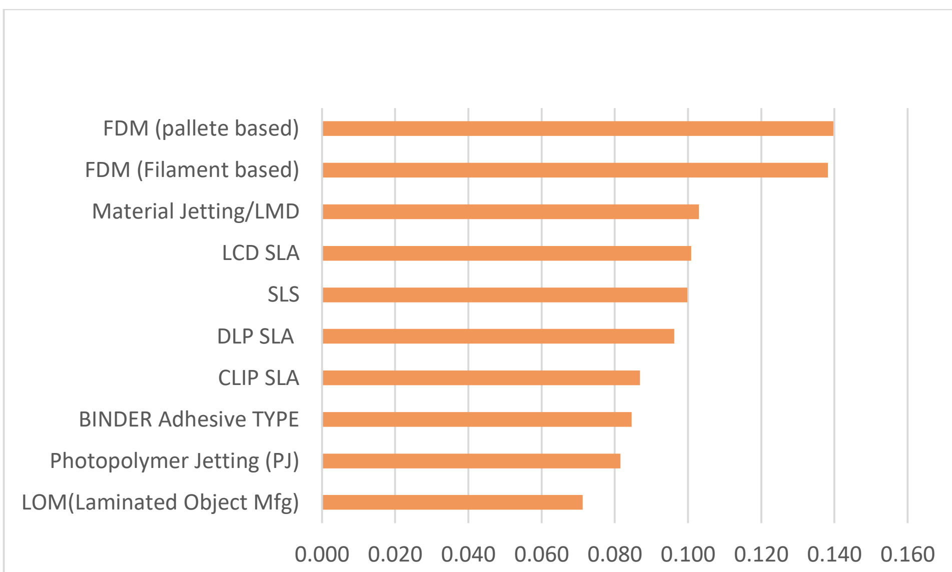


Figure 4-18: The ranking of technologies as estimated by review from expert 4

Table 4-20: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 5

	Dimensiona l Accuracy	Mechanical properties	Manufacturin g cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.082	0.106	0.123	0.095	0.058	0.045	0.083	0.135	0.037	0.082	0.051	0.048	0.055		
LOM	0.078	0.064	0.058	0.087	0.043	0.069	0.081	0.050	0.089	0.172	0.094	0.101	0.135	0.082	10
CLIP SLA	0.088	0.086	0.087	0.067	0.107	0.083	0.084	0.073	0.098	0.072	0.186	0.063	0.087	0.087	8
PJ	0.093	0.153	0.087	0.082	0.121	0.094	0.064	0.088	0.096	0.073	0.041	0.042	0.054	0.087	7
LCD SLA	0.046	0.058	0.112	0.060	0.045	0.158	0.050	0.135	0.126	0.047	0.127	0.053	0.066	0.083	9
SLS	0.105	0.101	0.082	0.101	0.153	0.068	0.126	0.100	0.101	0.068	0.078	0.168	0.050	0.099	6
BINDER Adhesive	0.112	0.167	0.058	0.118	0.098	0.051	0.130	0.074	0.053	0.079	0.085	0.139	0.180	0.103	4
Material Jetting	0.091	0.143	0.109	0.094	0.113	0.081	0.081	0.098	0.037	0.180	0.050	0.107	0.113	0.105	3
DLP SLA	0.120	0.068	0.080	0.161	0.071	0.166	0.127	0.057	0.142	0.104	0.162	0.061	0.061	0.100	5
FDM (Filament)	0.116	0.068	0.148	0.084	0.096	0.119	0.095	0.157	0.106	0.085	0.109	0.181	0.130	0.115	2
FDM (pallete based)	0.151	0.091	0.178	0.148	0.154	0.112	0.162	0.169	0.152	0.121	0.068	0.085	0.124	0.138	1

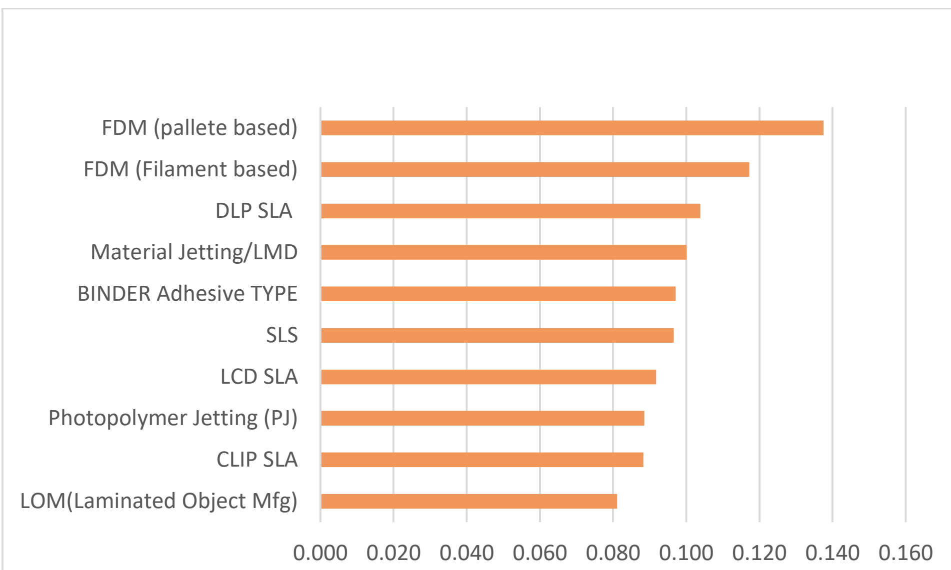


Figure 4-19: The ranking of technologies as estimated by review from expert 5

Table 4-21: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 6

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.114	0.08	0.118	0.052	0.032	0.095	0.129	0.102	0.07	0.043	0.059	0.045	0.06		
LOM	0.09	0.06	0.08	0.07	0.05	0.08	0.09	0.05	0.06	0.10	0.09	0.08	0.13	0.08	9
PJ	0.11	0.09	0.06	0.05	0.15	0.05	0.08	0.07	0.05	0.18	0.05	0.07	0.08	0.08	10
Material Jetting	0.07	0.12	0.09	0.05	0.11	0.07	0.09	0.12	0.05	0.08	0.07	0.09	0.15	0.09	7
CLIP SLA	0.07	0.11	0.07	0.06	0.08	0.13	0.07	0.08	0.10	0.08	0.15	0.09	0.11	0.09	6
BINDER Adhesive	0.12	0.15	0.04	0.08	0.08	0.06	0.12	0.07	0.08	0.08	0.07	0.19	0.13	0.10	5
LCD SLA	0.04	0.06	0.13	0.08	0.04	0.10	0.06	0.14	0.16	0.06	0.13	0.04	0.06	0.09	8
SLS	0.11	0.17	0.10	0.16	0.13	0.06	0.10	0.10	0.10	0.07	0.11	0.14	0.09	0.11	4
DLP SLA	0.10	0.10	0.11	0.11	0.10	0.17	0.16	0.05	0.11	0.15	0.09	0.06	0.09	0.11	3
FDM (Filament)	0.11	0.04	0.16	0.18	0.10	0.16	0.08	0.16	0.15	0.10	0.17	0.13	0.04	0.12	2
FDM (pallete based)	0.17	0.11	0.16	0.15	0.15	0.12	0.15	0.16	0.16	0.11	0.08	0.11	0.12	0.14	1

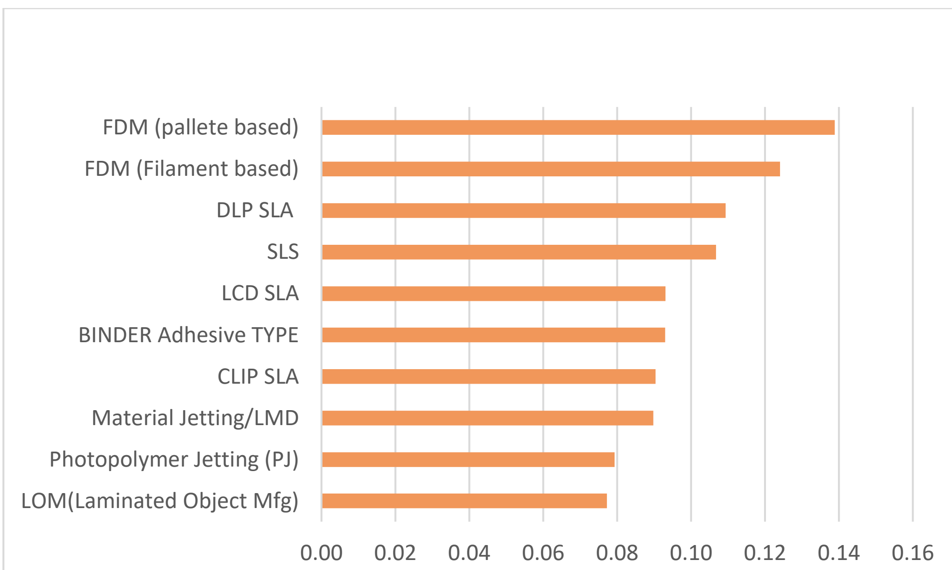


Figure 4-20: The ranking of technologies as estimated by review from expert 6

Table 4-22: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 7

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.11	0.097	0.07	0.034	0.034	0.099	0.079	0.126	0.09	0.122	0.038	0.052	0.048		
BINDER Adhesive	0.094	0.132	0.053	0.067	0.088	0.051	0.052	0.068	0.049	0.074	0.053	0.110	0.135	0.077	10
LOM	0.083	0.057	0.072	0.090	0.041	0.091	0.077	0.042	0.081	0.097	0.132	0.082	0.120	0.079	9
PJ	0.077	0.114	0.034	0.066	0.136	0.068	0.073	0.118	0.069	0.097	0.049	0.057	0.053	0.082	8
CLIP SLA	0.092	0.099	0.085	0.075	0.115	0.076	0.069	0.102	0.075	0.069	0.107	0.161	0.105	0.091	7
DLP SLA	0.104	0.062	0.114	0.108	0.080	0.105	0.107	0.048	0.111	0.159	0.088	0.080	0.093	0.098	4
Material Jetting	0.071	0.173	0.091	0.051	0.127	0.076	0.062	0.108	0.058	0.105	0.054	0.087	0.188	0.097	6
SLS	0.157	0.124	0.085	0.103	0.125	0.070	0.093	0.094	0.088	0.070	0.101	0.141	0.049	0.099	3
LCD SLA	0.044	0.055	0.106	0.141	0.056	0.145	0.148	0.145	0.127	0.054	0.139	0.053	0.068	0.098	5
FDM (pallete based)	0.153	0.123	0.162	0.139	0.130	0.155	0.163	0.104	0.152	0.105	0.096	0.125	0.127	0.133	2
FDM (Filament)	0.124	0.061	0.198	0.159	0.102	0.163	0.157	0.171	0.189	0.169	0.181	0.104	0.062	0.145	1

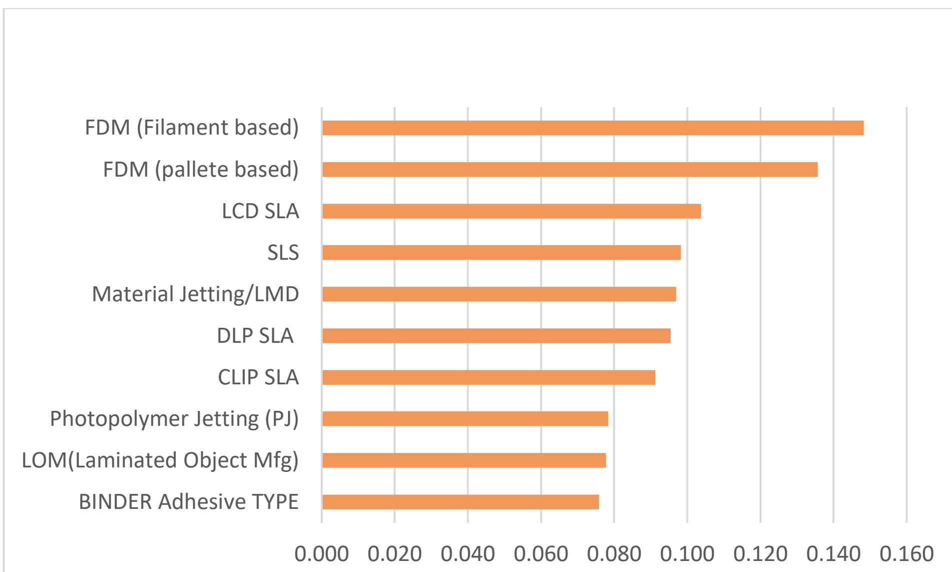


Figure 4-21: The ranking of technologies as estimated by review from expert 7

Table 4-23: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 8

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.131	0.103	0.038	0.063	0.037	0.109	0.124	0.108	0.076	0.052	0.044	0.041	0.072		
FDM (Filament)	0.095	0.062	0.158	0.117	0.076	0.116	0.098	0.145	0.099	0.135	0.162	0.178	0.095	0.1113	3
DLP SLA	0.116	0.063	0.064	0.116	0.072	0.16	0.197	0.076	0.188	0.097	0.106	0.045	0.071	0.1151	2
BINDER Adhesive	0.113	0.158	0.056	0.116	0.097	0.068	0.055	0.065	0.059	0.066	0.055	0.142	0.17	0.0938	6
LCD SLA	0.043	0.059	0.086	0.085	0.079	0.147	0.142	0.141	0.124	0.047	0.132	0.051	0.069	0.0968	5
SLS	0.124	0.093	0.114	0.138	0.134	0.052	0.096	0.103	0.1	0.071	0.093	0.176	0.045	0.0983	4
LOM	0.068	0.054	0.105	0.073	0.06	0.063	0.083	0.046	0.088	0.146	0.086	0.099	0.125	0.0785	10
Material Jetting	0.089	0.172	0.094	0.039	0.101	0.071	0.031	0.103	0.032	0.105	0.068	0.107	0.135	0.0869	8
PJ	0.082	0.111	0.082	0.077	0.133	0.096	0.065	0.079	0.074	0.103	0.056	0.054	0.078	0.0834	9
FDM (pallete based)	0.182	0.129	0.176	0.155	0.16	0.124	0.148	0.167	0.15	0.167	0.065	0.074	0.076	0.1409	1
CLIP SLA	0.087	0.098	0.067	0.083	0.086	0.102	0.085	0.076	0.086	0.063	0.177	0.073	0.137	0.0928	7

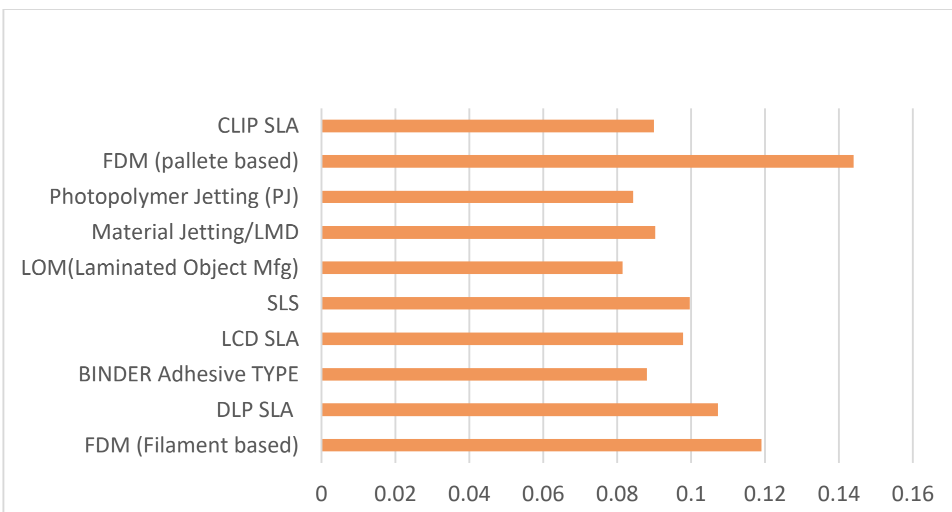


Figure 4-22: The ranking of technologies as estimated by review from expert 8

Table 4-24: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 9

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate	Weight	Rank
	0.084	0.103	0.031	0.037	0.127	0.101	0.081	0.132	0.089	0.063	0.044	0.054	0.055		
LOM	0.082	0.06	0.055	0.054	0.065	0.088	0.051	0.044	0.062	0.088	0.088	0.095	0.125	0.0708	10
PJ	0.085	0.111	0.062	0.065	0.145	0.076	0.153	0.077	0.047	0.111	0.041	0.046	0.084	0.0917	7
CLIP SLA	0.088	0.074	0.083	0.081	0.08	0.08	0.084	0.092	0.068	0.09	0.124	0.064	0.092	0.0834	9
Material Jetting	0.067	0.107	0.081	0.042	0.113	0.061	0.106	0.112	0.054	0.092	0.085	0.116	0.163	0.0942	6
BINDER Adhesive	0.121	0.168	0.047	0.105	0.083	0.061	0.080	0.096	0.069	0.085	0.054	0.146	0.127	0.0974	5
LCD SLA	0.043	0.055	0.125	0.085	0.044	0.109	0.041	0.147	0.166	0.058	0.159	0.062	0.073	0.0884	8
DLP SLA	0.096	0.091	0.106	0.141	0.09	0.164	0.103	0.059	0.116	0.15	0.095	0.054	0.088	0.1018	4
SLS	0.114	0.177	0.089	0.099	0.118	0.067	0.131	0.078	0.105	0.051	0.105	0.177	0.074	0.1077	3
FDM (Filament)	0.108	0.057	0.182	0.17	0.1	0.138	0.103	0.16	0.146	0.169	0.181	0.153	0.043	0.1252	2
FDM (pallete based)	0.196	0.101	0.171	0.158	0.162	0.156	0.149	0.136	0.168	0.106	0.068	0.088	0.131	0.1409	1

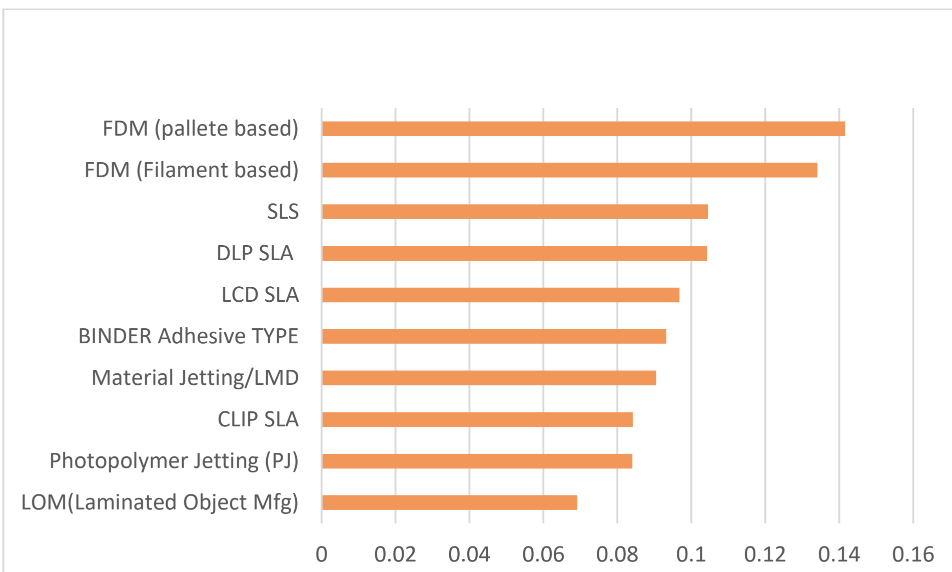


Figure 4-23: The ranking of technologies as estimated by review from expert 9

Table 4-25: Weightage calculation summary of the different 3D printing technologies, criteria based opinion of expert 10

	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing	RM Availability	Technical know-how	Initial setup cost	Technology maintenance	Safety & Risk Level	Energy consumption	Material variety	Production rate		
	0.084	0.103	0.031	0.037	0.127	0.101	0.081	0.132	0.089	0.063	0.044	0.054	0.055	Weight	Rank
LOM	0.082	0.06	0.055	0.054	0.065	0.088	0.051	0.044	0.062	0.088	0.088	0.095	0.125	0.0708	10
PJ	0.085	0.111	0.062	0.065	0.145	0.076	0.153	0.077	0.047	0.111	0.041	0.046	0.084	0.0917	7
CLIP SLA	0.088	0.074	0.083	0.081	0.08	0.08	0.084	0.092	0.068	0.09	0.124	0.064	0.092	0.0834	9
Material Jetting	0.067	0.107	0.081	0.042	0.113	0.061	0.106	0.112	0.054	0.092	0.085	0.116	0.163	0.0942	6
BINDER Adhesive	0.121	0.168	0.047	0.105	0.083	0.061	0.080	0.096	0.069	0.085	0.054	0.146	0.127	0.0974	5
LCD SLA	0.043	0.055	0.125	0.085	0.044	0.109	0.041	0.147	0.166	0.058	0.159	0.062	0.073	0.0884	8
DLP SLA	0.096	0.091	0.106	0.141	0.09	0.164	0.103	0.059	0.116	0.15	0.095	0.054	0.088	0.1018	4
SLS	0.114	0.177	0.089	0.099	0.118	0.067	0.131	0.078	0.105	0.051	0.105	0.177	0.074	0.1077	3
FDM (Filament)	0.108	0.057	0.182	0.17	0.1	0.138	0.103	0.16	0.146	0.169	0.181	0.153	0.043	0.1252	2
FDM (pallete based)	0.196	0.101	0.171	0.158	0.162	0.156	0.149	0.136	0.168	0.106	0.068	0.088	0.131	0.1409	1

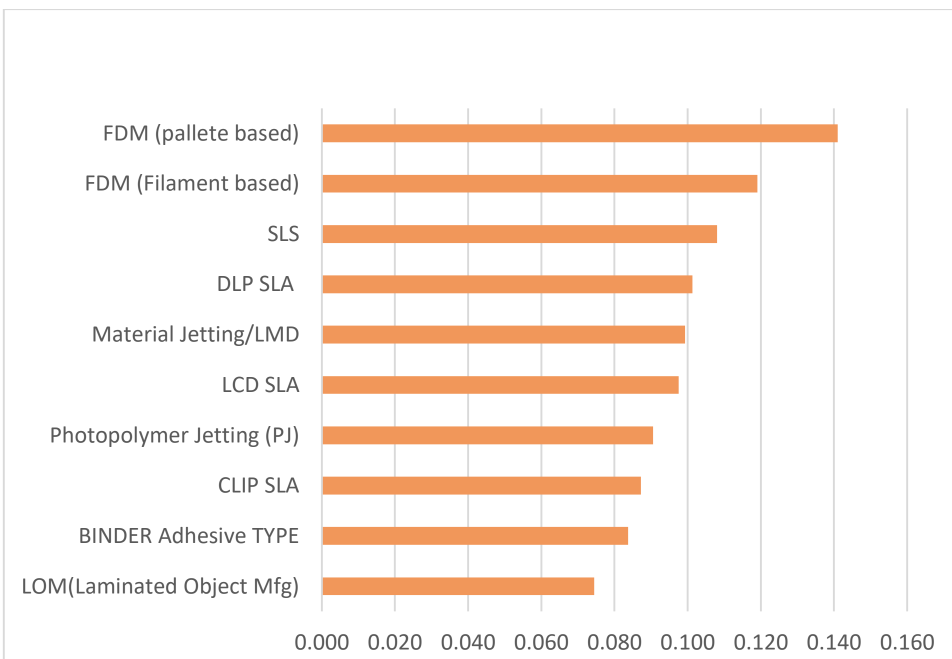


Figure 4-24: The ranking of technologies as estimated by review from expert 10

4.4 Final Decision Estimation

As this research work focuses on the technology deployment in Bangladesh, the moving average method is applied to identify the most feasible ranks of 3D printing technologies in Bangladesh. By this method, more weightage is given to the data from the expert who is more relevant to the country's scenario. In this way the decision will be more efficient and hence more suitable for respective technology deployment in the country.

Table 24 shows the weightages assigned to different experts for the calculation of weighted moving average according to their knowledge and experience of the industry.

Table 4-26: Weights assigned to experts for the calculation of weighted moving average

	Expert1	**Expert2**	**Expert3**	**Expert4**	**Expert5**	**Expert6**	**Expert7**	**Expert8**	**Expert9**	**Expert10**
Weightage percentage	30%	10%	5%	5%	15%	5%	10%	5%	10%	5%

The final weightages of multiple technologies are calculated using the weighted moving average and their respective ranks are assigned. Table 21 depicts the final calculated weightages and ranks.

The data from all the experts is used to calculate the weights of the technologies according to different criteria and rank them. All the final calculated weightages of various technologies as suggested by the experts in given in Table 4-27. The FDM technology shows the best performance in most of the cases followed the SLA technology. Also LOM and PJ generally show the least weightages.

Table 4-27: Summarized calculated weightage for all surveyed experts

	Expert1	Expert2	Expert3	Expert4	Expert5	Expert6	Expert7	Expert8	Expert9	Expert10	Final weightage	Rank
FDM (Filament based)	0.133	0.131	0.131	0.138	0.117	0.124	0.148	0.119	0.134	0.119	0.13047	2
DLP SLA	0.101	0.102	0.107	0.096	0.104	0.109	0.095	0.107	0.104	0.101	0.10210	4
BINDER Adhesive TYPE	0.064	0.087	0.081	0.085	0.097	0.093	0.076	0.088	0.093	0.084	0.08091	9
LCD SLA	0.139	0.092	0.101	0.101	0.092	0.093	0.104	0.098	0.097	0.098	0.10925	3
SLS	0.066	0.096	0.106	0.100	0.097	0.107	0.098	0.100	0.105	0.108	0.09003	8
LOM(Laminated Object Mfg)	0.048	0.089	0.075	0.071	0.081	0.077	0.078	0.081	0.069	0.074	0.06898	10
Material Jetting/LMD	0.101	0.087	0.092	0.103	0.100	0.090	0.097	0.090	0.090	0.099	0.09656	5
Photopolymer Jetting (PJ)	0.108	0.080	0.077	0.082	0.089	0.079	0.078	0.084	0.084	0.091	0.09055	7
FDM (pallete based)	0.139	0.149	0.137	0.140	0.137	0.139	0.136	0.144	0.142	0.141	0.14009	1
CLIP SLA	0.103	0.089	0.095	0.087	0.088	0.090	0.091	0.090	0.084	0.087	0.09306	6

It can be observed from the table that the FDM (Pallet based) and FDM Filament based can give us the best results. LCD SLA and DLP SLA also very prospective due to its fine finish and dimensional accuracy feature. It should be noted that LOM can be use its specific types of work it will not so good for diversified works.

Table 4-28: final weightages of multiple technologies are calculated using the weighted moving average

3D Printing Technology	Final Weightage calculated from weighted moving average method	Rank Achieved
FDM (pallet based)	0.14009	1
FDM (Filament based)	0.13047	2
LCD SLA	0.10925	3
DLP SLA	0.1021	4
Material Jetting/LMD	0.09656	5
CLIP SLA	0.09306	6
Photopolymer Jetting (PJ)	0.09055	7
SLS	0.09003	8
BINDER Adhesive TYPE	0.08091	9
LOM	0.06898	10

From the summarized calculation and analysis we can see that most of expert has the similarities in opinion based for FDM technology. Most of the experts preferred the FDM technology for Bangladesh. But there is some contraction among them to selection of FDM pallet based or FDM Filament. Finally the maximum weightage & highest rank gained by FDM pallet based technology.

We can conclude here by saying over several years additive manufacturing has grown and displaced traditional methods. Present market was occupied by 3D printers in rapid prototyping field. Numerous examples are indicated where additive manufacturing has entered new markets and picked up larger part advertise. In this task we investigate the use of additive manufacturing over customary assembling and the possibility of the disturbance of conventional techniques like injection molding. The possibility is dictated by a similar examination of the cost to influence parts according to bunch premise. We at that point decided the make back the initial investment point and the relationship to the general cost structure.

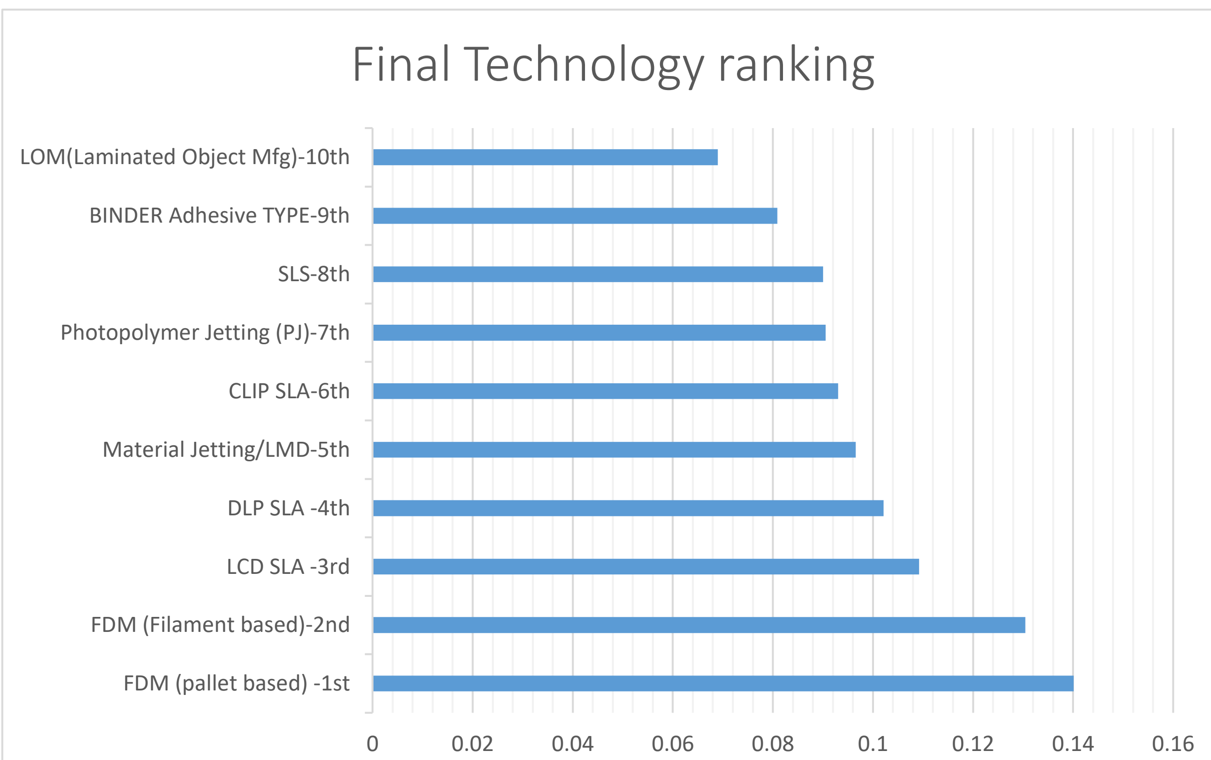


Figure 4-25: Final ranking for different types of polymer based 3D Printing Technology.

4.5 Financial Benefit of 3d Printing Technology

In this part of the thesis providing the case study data of application of 3D printing technology has been provided. Also provided the financial comparison with the traditional manufacturing. From that comparison we can take decision to adopt the additive manufacturing technology in Bangladesh.

3D printing technology can be used in different industries for diversified applications. Each industry has its own feature and uses AM to improve the efficiency of the process or enhance the performance of the products. The Scientific Bulletin of VALAHIA University-MATERIALS and MECHANICS conducted a research in which 3D Printing companies were asked to indicate what percentage of revenue came from which industry. As can be seen in Figure 26 the industrial/business machines is the largest industry which are using most 3D Printing technology, closely followed by the consumer products and electronics industries. The consumer products include many types of products from educational items, toys, kitchen tools, entertainment items etc. 3D printing is often used for prototyping to accelerate the speed of the product development in industries. Two other industries where 3D printing can be used worth mentioning are the motor vehicles and the medical/ dental industry. The motor vehicles includes automotive, Formula 1 and motorized sports, the focus for end-use products is often on reducing weight with the use of topological optimization. The medical industry is using 3D printing for making models, prosthetics and orthopedic implants for example skull, hip and knee implants. The dental medical bones purpose have difficulties with long lead times and the labor intensiveness of making orthodontic aligners, crowns and bridges. With 3D printing this process can be made more responsive and efficient, with advanced 3D scanning tools these products can be produced faster. In the aerospace industry the use of AM is interesting because the weight of parts can be reduced and complex assemblies can be consolidated in simple parts. At this moment 3D printing is only used in parts that are not mission critical because the parts cannot be fully certified.

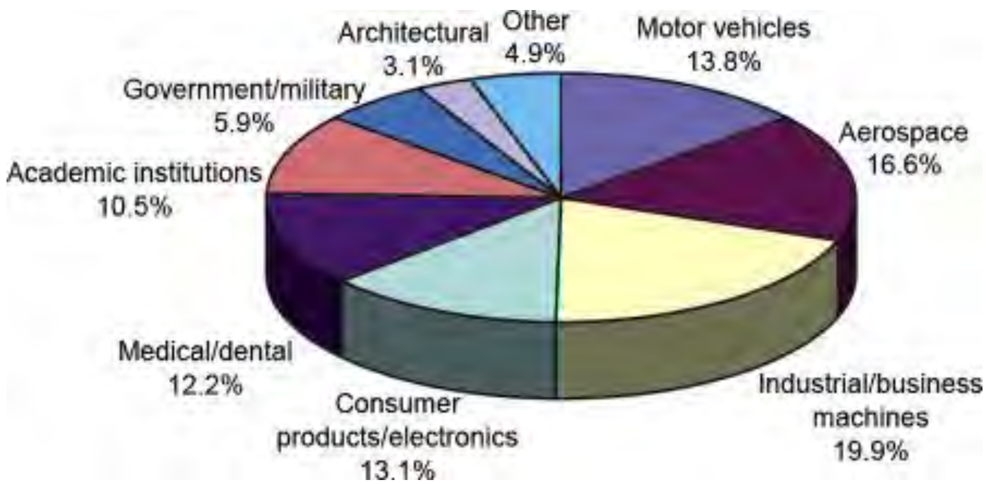


Figure 4-26: Graphical presentation of 3D Printing application in different industries

The financial effects of this technology in Bangladesh are very vast and the investment judgments in 3D technology are highly crucial and strategic. 3D printing is a promising technology and has a great potential to revolutionize the industrial sector of Bangladesh and effecting the financial structure as well. The major focus to integrate 3D printing in industry is the specific business objectives. Be it I the improvement of health and safety, reducing dependency on suppliers for risk minimizing or transforming the uptime, a business can build a strong business case by using these business objectives. Also it is tricky for the businesses that although the awareness is on the rise but it still has questions relating to how to move forward.

The small scale business in Bangladesh can benefit a lot from this technology. Small tools can be printed at site instead of ordering remotely which results in tool development cost, reduction in development time and saves delivery time and fuelling cost too. It is very faster to build these parts than to outsource them which is beneficial for these business.

The major advantage of the introduction of these printers in industry is the manufacturing of new customized products without increasing the costs. The AM technology has major effects on the costs of individualization, marginal production costs, capital costs and flexibility.

The introduction of 3D manufacturing technology in Bangladesh comes with a lot of limiting factors as well. The material availability is very low and limiting. The speed of production is low, which do not affect the small scale industries of Bangladesh but can affect the large or medium scale businesses. Also the developed parts still need another surface finishing touch.

The market effects of 3D printing technology are many fold. There is a growing population in Bangladesh which is interested in developing and providing services of 3D development, selling the 3D manufactured products and even developing their own printers to be used at homes.

From a collective outlook, the 3D printing is very helpful in the Bangladesh markets where the environments have a greater demand of customization, design complexity is high, flexibility is required or the delivery cost of products are very high. As the design and models can be optimized according to customer demand, the customer perception of product value is increased and hence they are willing to pay for the product. 3D printing also enables clients and the manufacturers to co–design a product fitting perfectly to their demands. This increase the number of product varieties available in the market and hence the demand increases. This type of production procedure in Bangladesh will not incur additional manufacturing cost and no penalties are related to higher number of product varieties.

The 3D manufacturing in Bangladesh will also affect the decision related to location of manufacturing facilities. As the machine setup cost is very low as compared to large set ups and take up very less space they can be placed very near to the point of use hence avoiding the large cost of transportations. This is especially good for the Bangladesh industry where the cost of transportation surpasses the cost of production in terms of raw material transportation, production or the product delivery. This type of production is also beneficial in those Bangladesh industries where there is a high demand of part replacement. These parts can be built on site and replaced saving cost, time and labor. The new 3D manufacturing services in Bangladesh are anticipated to facilitate the newbies easy access to local markets which reduces the barriers for market entry and encourages new business set ups.

4.5.1 Case study on financial evaluation 3d printing for small batch production for SME

One of the largest 3D Printing Company Icube Ltd. made different 3D printed parts for new design of control box and battery lock for Solshare:

	Dimension : 220x110x60 mm Material: ABS Application: Battery Lock Solar system Manufacturer: Icube Ltd. Customer Reference: Hannes, CTO- Solshare

Figure 4-27: Solar Control box small batch production for Solshare Ltd.

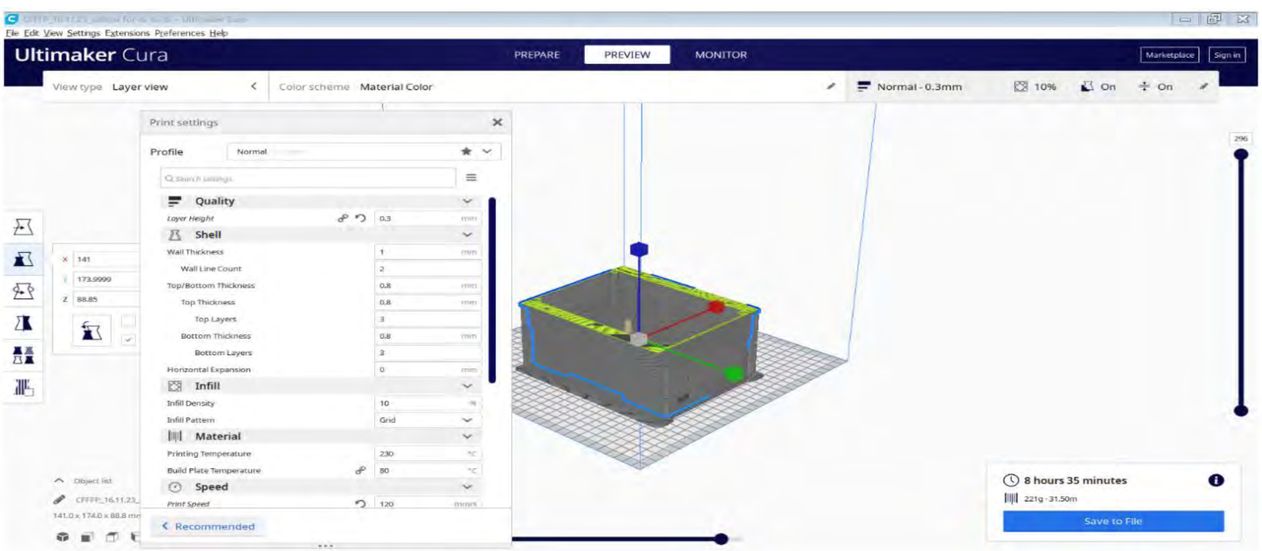


Figure 4-28 : Solcontrol Box .stl file settings through Ultimaker _CURA Version 4.5

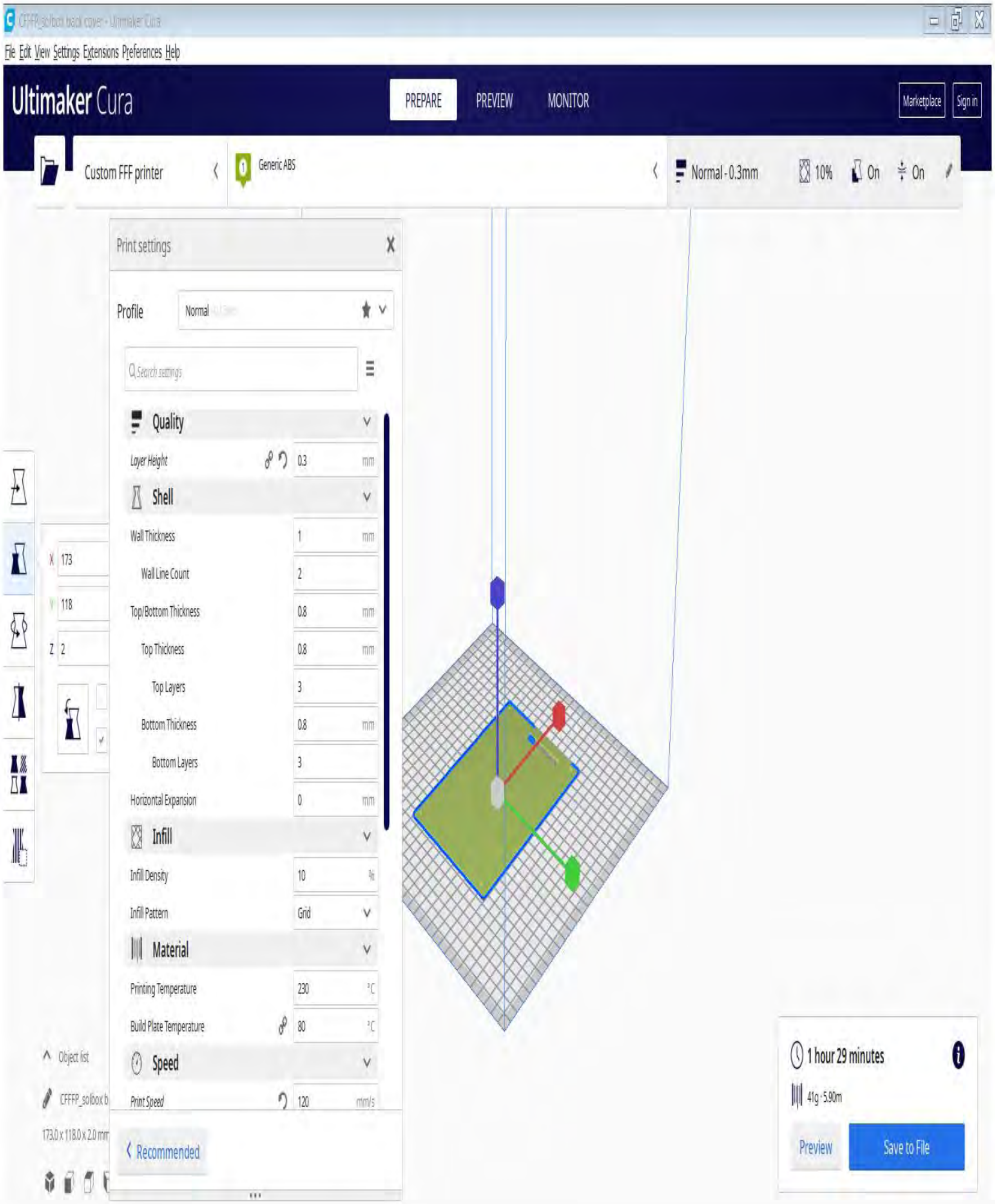


Figure 4-29: Solcontrol Cover .stl file settings through Ultimaker _CURA Version 4.5

Table 4-29: Cost calculation for SOLCONTROL Box & Cover manufacturing through 3D printing technology

Item Name	**SOLCONTROL Box & Cover**
Printer Type	Filament based FDM 3D printer
Printer Brand & Manufacturer	Hypercube(Icube ltd.)
Material	ABS

Material cost per kg (On the basis of per spool filament local price)	BDT 1,600.00		
Material cost per gm (based on filament spool price)	BDT 1.60		
Required material for printed object (Calculated from 3D .stl design by Cura 3D printing software including support material)	260 gm		
Total Material cost for printed object	BDT 416		
Direct labor cost per hr	BDT 25.00		
Total Direct labor hr (Estimate to set up the build, prepare the machine, & post-process the part.)	3 hrs		
Total Direct labor cost per part	BDT 75.00		
Machine cost/hr (Calculated from the machine investment over the years; provided calculation the bottom section)	BDT 16.2		
Total Machine hr (for producing the specific product mentioned Sol Box & Cover)	10.1 hrs		
Total Machine cost per part	BDT 163.6		
Manufacturing Overhead (% of Sub-total cost per part)	10%		
Manufacturing Overhead cost	BDT 65.46		
Sub-total cost per part(Material cost Machine Cost)	BDT 654.6		
Total cost per part	BDT 720		
Production Quantity(I have shown calculation for three different slots of manufacturing to evaluate economic manufacturing quantity through AM)	200 sets	400 sets	500 sets
Cost savings per part (compared to traditional manufacturing through injection molding; calculation shown in below section)	BDT 941	BDT 115.9	BDT 49.08

Table 4-30 : Cost calculation for SOLCONTROL Box & Cover manufacturing through Traditional Manufacturing

Traditional Manufacturing cost evaluation			
Material	ABS Pallet	ABS Pallet	ABS Pallet
Total unit	200	400	500
Material cost per gram	1.4	1.4	1.4
Material required per unit (gm)	205	205	205
Total Material required	41000	71750	102500
Material Cost per unit	287	287	287
Total Material Cost	57400	100450	143500
Mold Cost(Box +Cover)	295000	295000	275000
Overhead Cost (10%)	2050	3588	5125
Total Cost	297337	298875	280412
product cost per unit	1486.68	853.93	560.82
Total product cost	243460	337300	360761

*Injection molding considered as rental service

Table 4-31: Projected financial results for estimated production quantity

Number of Year	Investment: BDT 175,000.00 Savings for production quantity 200 sets	ROI	IRR
1	BDT 565,151	223%	223%
2	BDT 565,151	546%	303%
3	BDT 565,151	869%	319%

Number of Year	Investment: BDT 175,000.00 Savings for production quantity 400 sets	ROI	IRR
1	BDT 69,551	-60%	-60%
2	BDT 69,551	-21%	-14%
3	BDT 69,551	19%	9%

Number of Year	Investment: BDT 175,000.00 Savings for production quantity 500 sets	ROI	IRR
1	BDT 29,449	-83%	-83%
2	BDT 29,449	-66%	-50%
3	BDT 29,449	-50%	-28%

3D printer cost including installation = BDT 165,000.00

Working days per year = 300 days

Runtime Hours per week = 6x12 = 72 hrs

Annual Run time (hrs) = 72x500= 3600

Machine Life (yrs) = 3 yrs

Lifetime Machine Hours = 3600x3 = 10800 hrs

Number of parts per year = 600

Life time number of parts = 600x3 = 1800 sets

Number of parts per week = 2*6= 12 (2 sets in a day)

Initial Warranty Period (yrs) = 1 year

Years of Ext. Warranty = 2 year

Annual Ext Warranty Cost = BDT 5,000.00

Sub-Total Ext. Warranty cost = BDT 10,000.00

Total Investment Over Machine Life = BDT 165,000.00 + BDT 10,000.00

= BDT 175,000.00

Machine cost per hour = BDT 16.2

We can concluded from above calculation that for this part up to 400 sets the FDM 3D Printing technology is very much feasible. But if the quantity is 500 it will not economically feasible in 3D printing Technology, in that case injection molding is much more cost effective than additive manufacturing.

Cost calculated based on the following assumptions:

- 3D printed product will get from a service provider (where considered Icube data)
- Injection molding machine will get as rental service
- Local mold maker (Vai Vai Engineering) will make the mold.
- Pallet will be purchased as 50 kg bag
- Both manufacturing process scenario considered from Icube cost point of view.

As per case study we can see that if the order quantity exceeds 400 sets it is financially feasible to consider the traditional manufacturing process, for up to 400 sets FDM 3D printing is good options. But before choosing traditional manufacturing it is very much important to validate the mold and product design through additive manufacturing process.

4.5.2 Case Study on Financial Benefit 3d Printing for Medical Implant:

One of the largest 3D Printing Company Icube Ltd. made human skulls directly from cityscan model:

Dimension : 70x50x60 mm

Material: PEEK

Application: Portion of skull (Medial Implant)

Manufacturer: Icube Ltd.

Customer Reference: Patient under Dr.Forhad & Dr. Monir Hosain Reza (National institute of Neurology).

Figure 4-30: 3d Printed portion of skull (Medical Implant)

Table 4-32: Cost calculation for Parts of Human body manufacturing through 3D printing technology

Item Name	**Parts of Human body**
Printer Type	Filament based FDM 3D printer (400 degree high temperature extruder)
Printer Brand & Manuafacturer	Z-bot (Icube ltd.)
Material	PEEK

Material cost per kg	BDT 60,000.00
Material cost per gm (based on filament 1 kg spool price)	BDT 60.00
Unit material for printed object (gm)	1 gm

Total Material cost for printed object(have to from 3D .stl design-City-scan by Cura 3D printing software including support material; here calculated only based on 1 gm of PEEK filament printing)	BDT 60.00
Direct labor cost per hr (Considered highly skilled labor)	BDT 500.00
Total Direct labor hr (Estimate to set up the build, prepare the machine, & post-process the part.)	1 hr
Total Direct labor cost per part	BDT 500.00
Machine cost/hr	BDT 109.26
Total Machine hr for per gm of PEEK filament printing	0.1 hr/gm
Total Machine cost per gm (Calculated from the machine investment over the years; provided calculation the bottom section)	BDT 10.93/gm printing
Manufacturing Overhead(%)	10%
Manufacturing Overhead cost	BDT 57.09
Sub-total cost per part	BDT 570.93
Total cost per part per gm of PEEK filament printing	BDT 628.02
Costing per gm of medical implants import	BDT 2,500.00
Cost savings per part per gm of PEEK filament printing instead of import	BDT 1,871.98

Table 4-33: Projected Financial Results for per gm of PEEK filament printing for parts of Human body

Number of Year	Investment : BDT 590,000.00	ROI	IRR
	Savings		
1	BDT 33,695,665	5611%	5611%
2	BDT 33,695,665	11322%	5709%
3	BDT 33,695,665	17033%	5711%

3D printer cost including installation = BDT 550,000.00

No. of Week per year = 50

Runtime Hours per week = 6x6 = 36 hrs

Annual Run time (hrs) = 36x50= 1800

Machine Life (yrs) = 3 yrs

Lifetime Machine Hours = 18000x3 = 5400 hrs

Total weight printed per year (gm) = 18000 gm (1gm printing by 0.1 hr)

Total weight printed per week (gm) = 360 gm

Initial Warranty Period (yrs) = 1 year

Years of Ext. Warranty = 2 year

Annual Ext Warranty Cost = BDT 20,000.00

Sub-Total Ext. Warranty cost = BDT 40,000.00

Total Investment Over Machine Life = BDT 550,000.00+ BDT 40,000.00

= BDT 590,000.00

Machine cost per gm = BDT 109.26

Table 4-34: Advantages of Additive Manufacturing Technology over Traditional Manufacturing Technology for parts of Human body

Additive Manufacturing	**Traditional Manufacturing**
Made in Bangladesh within only 3 days by FDM 3D printer	By traditional casting process it required more than a month. But still this kind of precise manufacturing is not possible in our country right now. This sector is completely dependent on import.
3D Printing cost was 628 BDT per gm	Minimum cost 2500 BDT per gm
99.99% product detailing achieved	Very difficult task to achieve more than 80% detailing
Printed directly from cityscan file	Need to regenerate the highly skilled designer
Dimensional accuracy ±0.01 mm	Very hard to achieve the accuracy within ±1.00 mm

As per above detail information it is easy to understand that Additive manufacturing not only financially feasible but also technically feasible than traditional solution.

4.5.3 Case Study on Financial Benefit 3d Printing for Cottage Industries

One of the largest 3D Printing Company Icube Ltd. made different types of block to replace traditional wooden blocks pattern.

Dimension : 6 inch x 4 inch

Material: ABS

Application: Block Printing

Manufacturer: Icube Ltd.

Customer Reference:: Cottage Industry(Block printing house)

Figure 4-31: Block printing process through 3D printing design block

Table 4-35: Cost calculation for Block printing design forma through Traditional Manufacturing

Item Name	Block printing design forma
Printer Type	Filament based FDM 3D printer
Printer Brand & Manufacturer	Karika (Icube ltd.)
Material	ABS

Material cost per kg(On the basis of per spool filament local price)	BDT 1,600.00
Material cost per gm (based on filament spool price)	BDT 1.60
Required material for printed object (Calculated from 3D .stl design by Cura 3D printing software including support material)	30 gm
Total Material cost for Block printing design forma (Dimension: 6 inch x 4 inch)	BDT 48.00
Direct labor cost per hr	BDT 25.00

Total Direct labor hr (Estimate to set up the build, prepare the machine, & post-process the part.)	0.5 hrs
Total Direct labor cost per part	BDT 12.50
Machine cost/hr (Calculated from the machine investment and holder cost over the years; provided calculation the bottom section)	BDT 14.04
Total Machine hr	1 hr
Total Machine cost per part	BDT 14.04
Manufacturing Overhead(%)	10%
Manufacturing Overhead cost	BDT 7.45
Sub-total cost per part(Material cost Machine Cost)	BDT 74.54
Total cost per part (including overhead cost)	BDT 81.99
Costing per block by Traditional Manufacturing (Price is take from regular market price of wooden design forma for block printing; dimension 6inch x 4inch)	BDT 200.00
Cost savings per part (compared to traditional manufacturing through carpenter; calculation shown in below section)	BDT 118.01

Table 4-36: Projected financial results for block printing design forma.

Number of Year	**Investment: BDT 151,600** Savings	**ROI**	**IRR**
1	BDT 424,822	180%	180%
2	BDT 424,822	460%	258%
3	BDT 424,822	741%	275%

3D printer cost including installation = BDT 140,000.00

No. of Week per year = 50

Runtime Hours per week = 6x12 = 72 hrs

Annual Run time (hrs) = 72x500= 3600

Machine Life (yrs) = 3 yrs

Lifetime Machine Hours = 3600x3 = 10800 hrs

Number of parts per year = 3600

Life time number of parts = 3600x3 = 10800 sets

Number of parts per week = 12*6= 72 (12 sets in a day)

Initial Warranty Period (yrs) = 1 year

Years of Ext. Warranty = 2 year

Annual Ext Warranty Cost = BDT 4,000.00

Sub-Total Ext. Warranty cost = BDT 8,000.00

Total Investment Over Machine Life = BDT 140,000.00 + BDT 8,000.00

= BDT 148,000.00

Cost of per design holder = BDT 1200
Estimated number of design holder sets over the year = 3 nos.
Total Investment over Machine Life with design holder cost = BDT 151,600.00
Machine cost per hour = BDT 14.04

Table 4-37: Advantages of Additive Manufacturing Technology over Traditional Manufacturing Technology for block printing design forma

Additive Manufacturing	Traditional Manufacturing
Made within only 1-3 hrs by FDM 3D printer	By traditional manual wood working process it required more than a day for Carpenter
3D Printing cost is below 100 BDT	Minimum cost 200-250 BDT
95% product detailing achieved	Very difficult task to to achieve more than 80% detailing
Printed directly from 3D design file	Need the highly skilled handicraft professional
Dimensional accuracy ±1.0 mm as per reduced drawing scale	Very hard to achieve the accuracy within ±5.00 mm

As per above detail information about this type of block printing model of Additive manufacturing not only financially feasible but also possible to get detail accurate and more realistic model it required to use 3D printing technology. But if anyone wants to use subtractive manufacturing process such as wood CNC router it may be closer with respect to cost effectiveness of 3D printing.

4.5.4 Case Study on Financial Benefit 3D Printing for Entertainment Industry

One of the largest 3D Printing Company Icube Ltd. made full castle for drama.

Dimension : 400x300x2500 mm

Material: ABS

Application: Castle for drama

Manufacturer: Icube ltd

Customer Reference: Dark room for drama “Shat via Champa”

Figure 4-32: 3D Printed castle for a drama named “Shat via Champa”

Table 4-38: Advantages of Additive Manufacturing Technology over Traditional Manufacturing Technology for Entertainment Industry

Additive Manufacturing	Traditional Manufacturing
Made in Bangladesh within 3 days by FDM 3D printer	By traditional process it required more than 14 days by Cork sheet handicrafts professional
3D Printing cost was 3500 BDT	Minimum cost 7000-10,000 BDT
95% product detailing achieved	Very difficult task to achieve more than 80% detailing
Printed directly from 3D design file	Need the highly skilled handicraft professional
Dimensional accuracy ±0.1 mm as per reduced drawing scale	Very hard to achieve the accuracy within ±10.0 mm

4.5.5 Case Study on Financial Benefit 3d Printing for Agricultural Industry

One of the largest 3D Printing Company Icube Ltd. made Krishibot, Hydroponic parts, automatic seeding

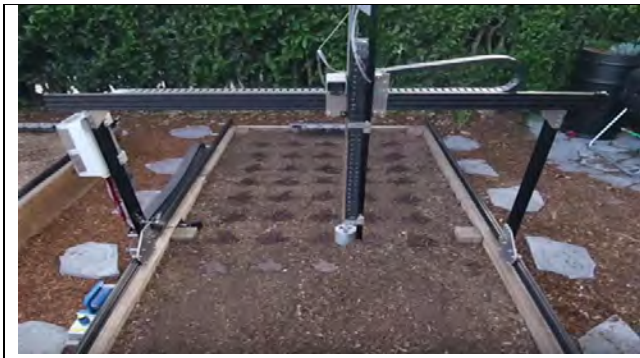
 	Dimension : Different size parts Material: ABS, ASA, HIPS Application: Hydroponic Tower, Seedbot Manufacturer: Icube Ltd. Customer Reference:: Sher-e-bangla Agriculture University

Figure 4-33: 3D Printed Krishibot, Hydroponic parts for Agricultural Industry

Table 4-39: Advantages of Additive Manufacturing Technology over Traditional Manufacturing Technology for Agricultural Industry

Additive Manufacturing	**Traditional Manufacturing**
Easy to manufacture parts of different types of Agricultural Automation equipment such as Seedbot for seeding, fish feeding and Hydroponic parts. By additive manufacturing process easy to make complex structure within a very short time which cost is 20 to 30% lesser than traditional manufacturing.	By traditional process it is costlier & time-consuming to make such kind of parts. Most of the cases not possible to make complex structures.

4.5.6 Case Study on Financial Benefit 3d Printing For Educational & Toys Industry

One of the largest 3D Printing Company Icube Ltd. making different types educational toys:

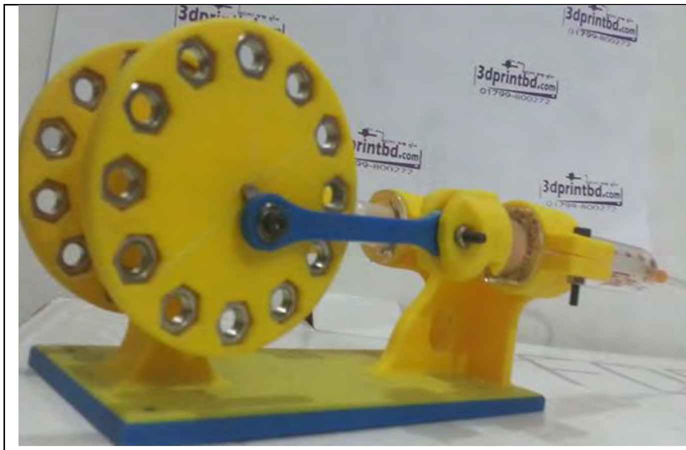
	Dimension : Different size parts Material: ABS, PLA, ASA Application: Sterling Engine Manufacturer: Icube Ltd. Customer: Retail Reference: 3dprintbd.com

Figure 4-34: 3d printed miniature Sterling Engine model

Table 4-40: Advantages of Additive Manufacturing Technology over Traditional Manufacturing Technology for Educational & Toys Industry

Factors	**Additive Manufacturing**	**Traditional Manufacturing**
Machine set up cost	Around 5 to & 7 lac is good enough for preliminary setup	Need 30 to 40 lac to require to preliminary machine setup
Labour Cost	2 to 3 Mid-level educated person is good enough for start-up	10 to 12 skilled professional required for start-up
Material cost	Filament based FDM technology material cost is 30% higher than Pallet based FDM.	Material cost is 30% lesser tha FDM Filament based technology
Production Time	Large production such as 500 pcs like attached image is not feasible by this technology.	Large production such as 500 pcs is not feasible by this technology.
Mold or Dye	No need any mold for this technology	Mold or Die cost is major cost of making this type of products
Market Analysis	Easy to analyse the market demand by making 100 to 200 sets.	Not possible analyse the market by making small quantity due to its high mold or dye making cost
Results & discussion: Additive Manufacturing can be the game changing technology in this sector. But for large scale production or business it is very important integrate both the technology in the production process.		

4.5.7 Case Study on Financial Benefit 3d Printing for Architectural Model

One of the largest 3D Printing Company Icube Ltd. made **Architectural Model Length 8 ft x width 4ft x height 14 inch** :

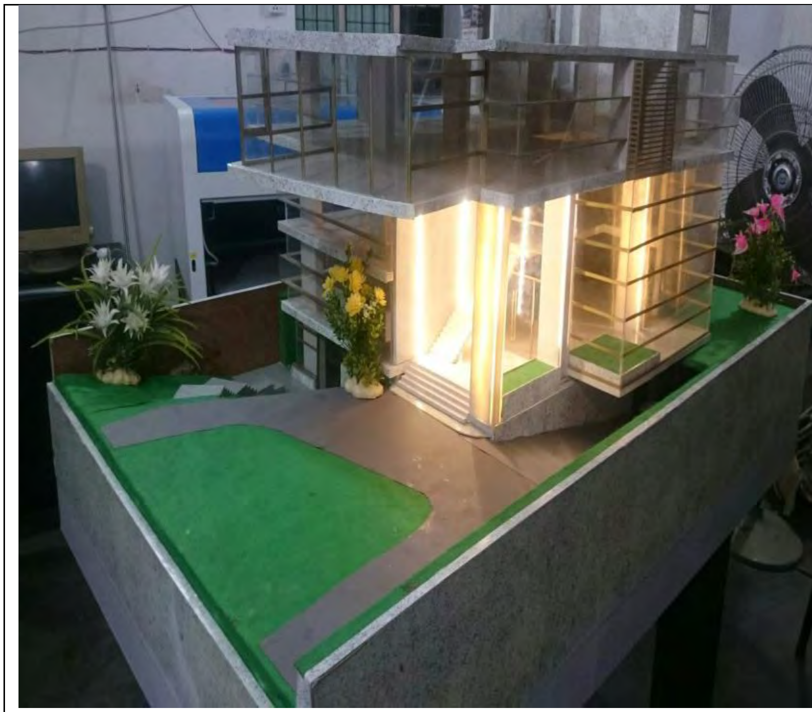
	Dimension : **Length 8 ft x width 4ft x height 14 inch** Material: ABS, PLA, ASA, Acrylic Application: Architectural Model Manufacturer: Icube Ltd. Customer Reference: Southbreeze Developers.

Figure 4-35: 3D printed model of "South Square-Gulshan"

Table 4-41: Advantages of Additive Manufacturing Technology over Traditional Manufacturing Technology for Architectural Model Making

Additive Manufacturing	Traditional Manufacturing
Made in Bangladesh within 25 days by FDM 3D printer	By traditional process it required more than 45 days which includes LED stripping inside the wall.
3D Printing cost was 250000 BDT	Minimum cost 150000 BDT
95% product detailing achieved	Very difficult task to to achieve more than 80% detailing
Printed directly from 3D design file	Need the highly skilled handicraft professional
Dimensional accuracy ±1.0 mm as per reduced drawing scale	Very hard to achieve the accuracy within ±5.00 mm

As per above detail information about this type of Architectural model of AM not so financially feasible but if anyone wants to get detail accurate and more realistic model which required to use 3D printing technology such as SLS, FDM, LOM multicolor 3D Printing.

4.5.8 Case Study on Financial Benefit of 3D Printing for New Product Development

One of the largest 3D Printing Company Icube Ltd. made different 3D printed parts for developing new design of roof top AC for Walton:

Dimension: 600x600x20 mm

Material: ABS

Application: Indoor AC parts

Manufacturer: Icube Ltd. (3dprintbd.com)

Customer reference: Walton, Engr. Aowal Hossain, Deputy Director, AC (R&D)

Figure 4-36: Walton roof top AC 3D printed parts

Walton made this part in year 2015 to change the design of roof top AC parts. This part size was very big Length 600 mm Width=600 mm, Height: 30 mm. Before going to manufacture final parts Walton made the prototype by 3D printing. Following benefits they gained from Additive Manufacturing instead of using traditional manufacturing system:

- Through AM it required 8 days to manufacture the product, on the other hand if they use the mold making it required more than 90 days.
- Easier and very low cost to validate the design. AM final cost is 17000 BDT.
- Not possible to use subtractive machining method like due to the requirements of final functionality check of the product.
- AM total cost was only 17000 BDT whereas TM process required more than 5, 50,000 BDT to make this mold.
- In AM no need to use highly skilled manpower, but in TM process required highly skilled manpower and experience as well.
- Very nominal amount of material waste if required to change the design in AM process, but in TM process need to replace mold which cost is around 5, 50,000 BDT.

Not only this part, Icube ltd. made so many parts for Walton R&D department such as Remote controller Casing, Robotic Arm Parts, Rice cooker, Blender parts etc. Though Walton has the Injection molding machine and mold making machine, before they start commercial production they taken service from Icube Ltd. to make prototype as well as market demand analysis.

4.6 Triple Helix Model for 3d Printing Technology Transfer in Bangladesh

This portion of the thesis examines the relationship among the actors of the Triple Helix Model namely, the government, higher educational institutions and the private sector. Here also shows the Technology Transfer process through Schumpeterian trilogy within the framework of Triple Helix.

To successfully adopt any new technology it is very much important to collaboration among Academia (Educational Institutions), Industry (Business sector) & Government.

In identifying the roles and interactions between different actors in the triple helix perspective and identifying how the innovation ecosystem works with the government support, this study use interview like discussions with relevant professional of Academia, Government & Industry. Discussions conducted with Government related officials, University researcher, Fablab professionals, & Additive Manufacturing company owner.

Based on the literature review and discussion with experts here proposed a triple helix framework activities that utilizes the literature to collate and group several attributes into a checklist to represent and to assess the level of linkage and activities undertaken

by each actor within the Triple Helix Model illustrated in Figure 1. The framework will be utilized to determine the degree of linkages within the Triple Helix Model for implementation of 3D printing technology.

In the diagram, three circles are showing the current activities of triple helix actors and comment circle are used for mentioning the collaboration between the actors.

Also provided a structured recommendation for individual actor to strengthening interactions and accelerate the implementation process effective and faster.

In the following diagram Proposed Triple Helix framework activities for implementation of 3D printing technology in respect of literature (66) and collected information from the relevant experts:

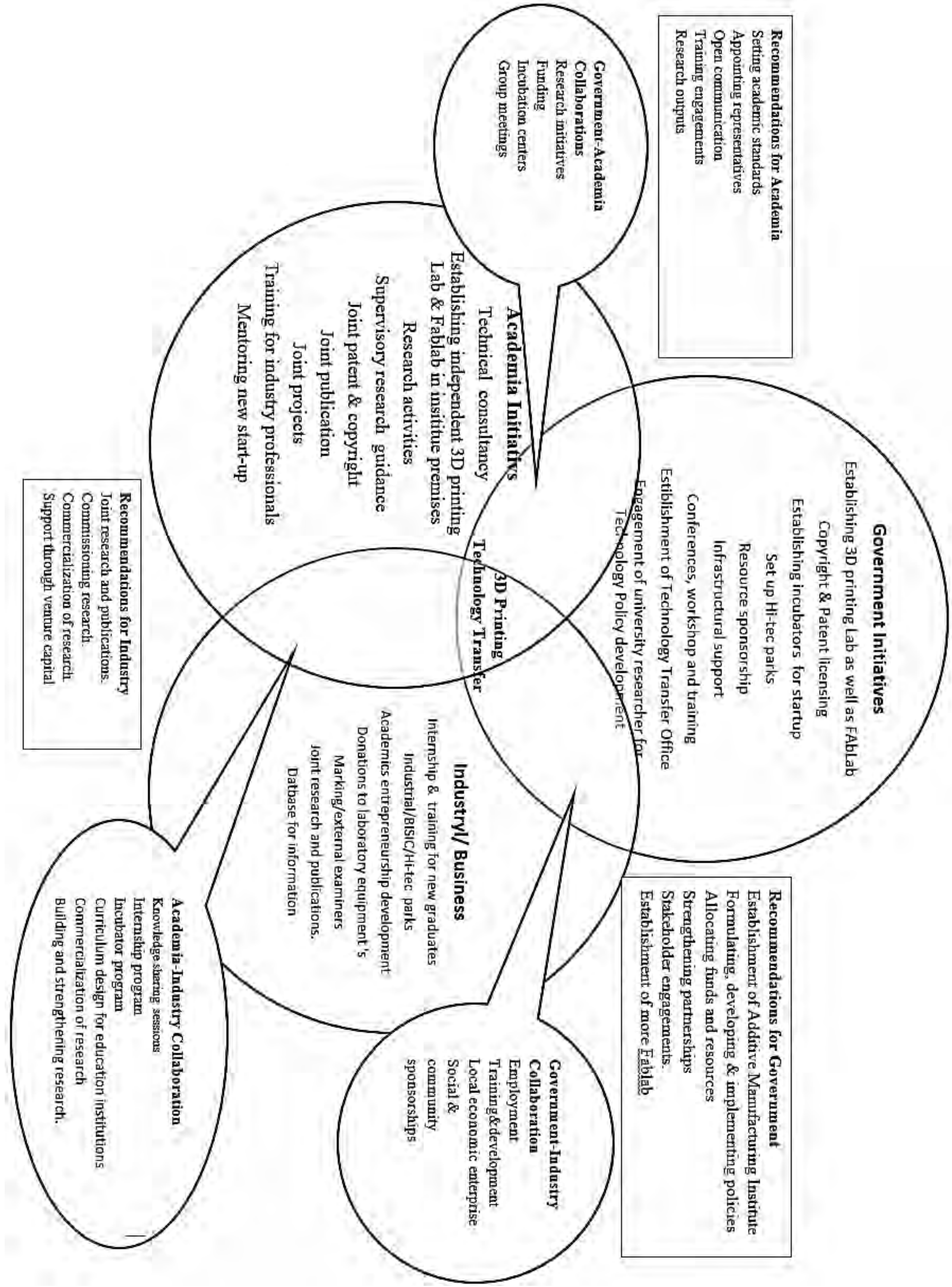


Figure 4-37: Individual & Collaborative activities of Triple Helix actors for 3D Printing Technology Implementation

4.6.1 Proposed government support within triple helix

To implement the 3D Printing technology in Bangladesh following support is very important from Government within TH framework:

- Joint research and publications on additive manufacturing sector.
- Research commissioning from Academia that is broad enough for commercialization.
- Formulating, developing, and implementing policies especially for 3D Printing technology.
- Providing workshops, incubators, and start-up funding to increase popularity among new entrepreneurs.
- Financing and funding pilot projects, research activities, commercialization, and incubation of innovations of 3D printing.
- Recognition & Awards for research pilots and commercialization.
- Legal protection with respect to Intellectual Property (IP) and patenting, copyright, production, manufacture, marketing, distribution of new innovative work of 3D printing technology.
- Facilitate various commercialization efforts through start-up funding.
- Strengthening network of open source community by building communication channels.
- Identify prospective Educational Institute and facilitating their development.
- Improving dissemination of research by supporting early innovations.
- Providing workshops for future developmental activities in this sector.
- Human resource development & capacity enhancement.
- Playing a critical role in rewarding and funding incentives, which should be offered to new entrepreneurs, organizations & individuals.
- Analyse international trends in policy development and implementation.
- Facilitate consultancy in predefined structured method.
- Regional and national co-ordination and support networks within open source community.

4.6.2 Proposed relationship among academia, industry & government

- Collaborative research agreement on additive manufacturing should be put in place.
- The government should set out a plan for identifying the specific needs of industry and Academia to implement this technology.
- Policies, collaborations, co-operation, and dedicated resources should be put in place to facilitate the relationship among the parties involved.
- Triple helix should ideally be that of each actor standing alone separately, whilst meeting on a regular basis
- Organize opportunities for researchers to identify current needs of the country manufacturing sector.
- Relationships among triple helix actors should be on the basis of equal partnerships and they must work together to drive technology implementation process.
- The triple helix actors should participate actively in shaping & organizing the national policy.

4.6.3 Benefits of Academia engaging with Industry/ Business Sector

- Financial assistance and funding of Academia activities for Additive Manufacturing sector.
- Implementation of practical, authentic & real life integrated learning on 3D printing technology.
- Increased prospects of students' internship, training, placement and employment.
- Supporting & Collaborative role of Academia activities – research, innovation incubation.
- The possibilities of facilitating mutually beneficial educational programs and courses relevant to market demand.
- Knowledge sharing programs –research, open source community development & engagements.
- Regular financially beneficial in terms of income, earning royalties.
- Effective utilization of opportunities for future networking should be utilized benefiting both the staff and students.

- Utilization of entrepreneurship spirit between the Academia and Industry sector.
- Possibility of human resource links including employment of fresh graduates and faculty members by the industry sector.
- More possibility of postgraduate research, which can be of commercial value.
- Funding R&D programs and commercialization of research outputs.
- Big opportunities for funding research to be translated into products and services.
- Economically viable investments taking place between Academia and industry/business sector.

4.6.4 Recommendations for Triple Helix actors

Based on the above study the following recommendations are proposed for strengthening the coordination and stimulating 3D printing technology implementation process:

- Large number of professionals of additive manufacturing should be trained to develop the requisite skills and competencies for strengthening the Triple Helix Model such as early identification of research opportunities, collaboration prospects, screening of relevant programs and assessment of potential activities.
- Government should play an important role in making available research and development hubs of additive manufacturing that will ensure transformation of concepts into products and services.
- Require to allocation of additional budget for the human resource needed in this emerging sector.
- Effective & responsive participation of the industrial sector in research commercialization and addressing complex sustainable development challenges which is facing the government as well as country should be structured.

4.7 TT Process of 3D Printing Technology in Bangladesh within TH Framework

In the Technology Transfer process Schumpeterian trilogy Diffusion, Invention & Innovation are very three important steps. The Schumpeterian trilogy divided the technological change process into three distinct phases:[64]

Invention phase: the technological change process including the conception of new ideas.

Innovation phase: the innovation process that involves the development of new ideas into marketable products and processes. "The doing of new things or the doing of things that are already being done in a new way."

Diffusion phase: the diffusion stage in which the new products and processes spread across the potential market.

In this part of this research we have identified the TT flow process in the triple helix framework through related literature review and interview with Icube Ltd. & Institute of appropriate technology, BUET & Bangladesh Hi-Tec park authority.

After study of sort out the bureaucracy, the lack of innovation and Entrepreneurship culture and the university's lack of experience on working in collaborative research; also company's lack of experience on working with the university (part of Academia). The importance of combining theory with practice, achieved through collaborative research to adopt new 3D printing technologies which is growing day by day. A university is the one supporting and encouraging innovation and entrepreneurship culture, helping government to reduce the bureaucracy within their activities, paying attention to the market and developing research based on this emerging 3D printing technology. Also helpful to generate new companies related with this technology.

The outside community not understand the function of research, which start from 3D printing design at the university level and goes to the final consumer as a product through the company, community only sees the university only as responsible for educating professionals. These collaborative projects is necessary in triple helix actors so that this culture of Innovation can complete the Schumpeterian trilogy in the perspective of technology Diffusion. The university-industry interaction fosters the connection between researcher and market, which, consequently, makes the professional more dynamic & responsive in the learning.

This study shows that universities and companies need to improve this interaction, thus generating more transfer cases in the application of 3D printing technology in different sectors which will increase the rate of inventions that become innovations. To adapting and diffusing the innovation culture, as companies also need to have access to these new 3D printing technologies so that they can acknowledge them and offer them to the market.

Regarding TT, the processes are not still established in Bangladesh, here is no clear and defined process for this type of hi-Tec technology transfer. The university needs to be entrepreneurial to foster the innovation culture. Also need to create internal policies in the innovation area and mapping transfer processes to reduce bureaucracy in these activities.

From this study, possible to summarize that the university–industry interaction process has been improving, but it still needs to advance in organizational aspects. It is important that companies and universities need to understand that they must join efforts in collaborative technological research, so that the financial resources invested are accepted into technological innovations accepted by the market. All this investment will return as new 3D printed products, services, 3D printer & technology that generate national impact, implementing new types of businesses and new markets as well for economic impact in the country which is shown in (Figure 30). Figure 30 shows the scientific contribution of this research. This figure focuses on the Schumpeterian trilogy technology transfer approach along with the triple helix framework about the university–business interaction. The triple helix actor government is shown representing the financial resources that encourage innovation in additive manufacturing sector and also the end point of diffusion that is the economic impact generated by innovation comes through this technology.

Financial resources, basic research and knowledge provided by the university allow the generation to invent new machines for this technology and new additive manufacturing technology inventions. All this invention combined with the company's ability to receive these products or services and transform them through the production on an industrial scale, combined with the diffusion of this technology. Possible to make new products, new services or new markets, hence contributing to society's welfare and national crisis time Corona pandemic.

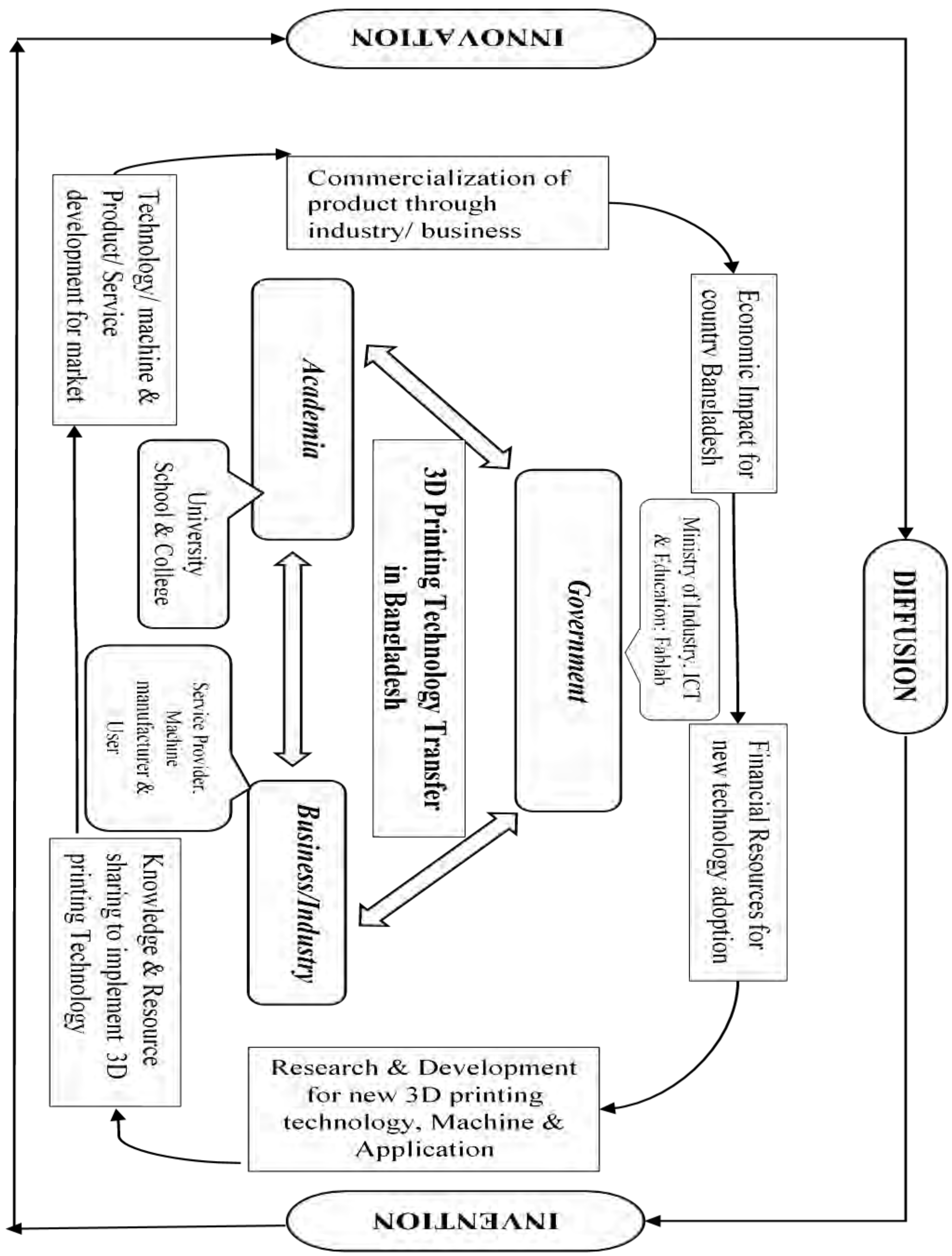


Figure 30: 3D Printing Technology transfer process among the Triple Helix actors; adopted from [65]

After discussion with relevant experts and policy maker I have been developed a matrix of contributor and possible area of contribution for implementation and promote 3D printing technology in Bangladesh.

Table 4-42: Matrix of Triple Helix contributor and possible area of contribution

Actors & Sub-Actors / Contribution Area	Academia		Government				Industry		
	University	School & College	Fablab	Industry Ministry	ICT Ministry	Education Ministry	Service Provider	Machine Manufac turer	User
Fund				**Y**	**Y**	**Y**			
Human resource	**Y**	**Y**	**Y**					**Y**	
Training	**Y**		**Y**	**Y**	**Y**			**Y**	
Incubation Centre				**Y**	**Y**				
Application R&D	**Y**		**Y**					**Y**	**Y**
Machine Manufacturing R&D	**Y**		**Y**					**Y**	
Equipment's				**Y**					
Technology Transfer Support	**Y**		**Y**	**Y**	**Y**				
Commercial				**Y**					
Legal & Administrative Support				**Y**	**Y**	**Y**			
Information centre				**Y**	**Y**	**Y**		**Y**	
New product development	**Y**		**Y**					**Y**	
Technology Awareness	**Y**	**Y**	**Y**	**Y**	**Y**				**Y**
Education	**Y**	**Y**	**Y**			**Y**			
Innovation	**Y**		**Y**	**Y**			**Y**	**Y**	
Market Development			**Y**	**Y**			**Y**	**Y**	**Y**

Note: Symbol **"Y"** is used here as the contribution area of Triple Helix actors.

CHAPTER 5: CONCLUDING REMARKS

In this study, with the use of AHP (technology assessment tool) based on surveyed data it has been found that in the current situation of Bangladesh market Pallet based and Filament based FDM 3D printing can be delivered highest performance. On the other hand LCD SLA and DLP SLA also very potential market for Bangladesh market but need to ensure availability of raw material and training. Without the large business conglomerate or big investor it is difficult to afford CLIP SLA & SLS, but hopefully after expire of technology patents price will be come down in reasonable value.

Photopolymer Jetting, Binder Adhesive type and Laminated Object Manufacturing technology should be used only specific application as well as for specific confirmed customer segment.

In the financial feasibility part of the study observed that most of the cases it is financially feasible to use Additive manufacturing process instead of traditional manufacturing process. But in the context of Bangladesh Industries & Labor cost it is suggested that if we can integrate the 3D printing techniques with the traditional manufacturing method possible get best outcomes from this technology.

Proper application of this technology strongly depends on collaboration among the major three players Academia, Government and industry. Also need to take responsibility by key players in their specific contribution area. Triple helix method will be very helpful to make the coordination easier.

CHAPTER 6: RECOMMENDATIONS

6.1 Recommendations for Bangladesh's Manufacturing Sector

Bangladesh's manufacturing sector is mainly depended traditional technologies which very costly, time consuming and low quality.

This study suggests that the development of the Manufacturing process in Bangladesh should aim at:

1. Integrate the 3D printing technology in existing manufacturing process which will make the process dynamic, efficient & responsive.

2. In the existing manufacturing scenario it is very important to select the appropriate 3D printing technology. According to this survey & analysis FDM (fused decomposition modelling technology) most possibly perform best for Bangladesh market. Between the two FDM technologies, Pallet based will be better than Filament base for Bangladesh market.

3. To implement SLA technology need to focus on raw material availability and proper training for literature people about this technology. LOM, PJ & BJ should be used to meet the specific customer need.

4. Despite of replacing the traditional manufacturing process by additive manufacturing it will be better and financially feasible to integrate the 3D printer in existing production line.

5. To adopt the 3D printing technology it is very much important to proper collaboration between Government, Academia & industry. Among the three key players Government role is very vital flourish the 3D printing industry to compete the Bangladeshi product in Global market.

6. Researcher are expecting that next industrial revolution will come through 3D printing technology. So it is quite impossible to think about next generation product without this game changing technology. To build "Digital Bangladesh" it is one of the major actor for developing digital fabrication concept.

6.2 Recommendation for Future Research

In this study I have identified the appropriate technology, but it also necessary to identify the critical success factor specific technology and possible improvement suggestion through transformation matrices like QFD (Quality Function Deployment). Specific suggestion can be provided through analyzing existing traditional manufacturing process and the way or scope of integration of additive manufacturing technology. Through AHP methodology also possible to determine the most appropriate 3D printing machine for specific application

In my study I have studied the finical feasibility of specific sectors but it also possible to analysis of Future economic impact of Additive manufacturing on total economy of a country through proven financial models. Also it is important to identify the most potential area to apply 3D printing technology. According to financial study next research can be done for specific and effective way of integration additive manufacturing in traditional manufacturing system.

To implement this AM technology I have shown the role of triple helix actors in broader sense but it can be possible to define their roles more specifically according to generation needs.

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APPENDIX A

PAIRWISE COMPARISON MATRIX CALCULATION

DIMENSIONAL ACCURACY

Expert-1

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	0.14	0.50	0.11	0.17	3.00	0.33	0.33	1.00	0.14	0.027	9
DLP SLA	7.00	1.00	3.00	0.50	4.00	9.00	3.00	3.00	7.00	1.00	0.178	3
BAT	2.00	0.33	1.00	0.11	0.50	2.00	0.50	0.50	0.14	0.17	0.035	8
LCD SLA	9.00	2.00	9.00	1.00	5.00	9.00	4.00	4.00	9.00	2.00	0.277	1
SLS	6.00	0.25	2.00	0.20	1.00	8.00	0.50	0.50	5.00	0.13	0.075	6
LOM	0.33	0.11	0.50	0.11	0.13	1.00	0.20	0.20	1.00	0.11	0.018	10
Material Jetting	3.00	0.33	2.00	0.25	2.00	5.00	1.00	1.00	2.00	0.50	0.075	4
Photopoly mer Jetting	3.00	0.33	2.00	0.25	2.00	5.00	1.00	1.00	2.00	0.50	0.075	4
FDM (pallet)	1.00	0.14	7.00	0.11	0.20	1.00	0.50	0.50	1.00	0.11	0.045	7
CLIP SLA	7.00	1.00	6.00	0.50	8.00	9.00	2.00	2.00	9.00	1.00	0.194	2

CI 0.040

Random 1.49

CR 0.0267

Expert-2

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	1.00	0.50	1.00	2.00	3.00	2.00	1.00	0.50	3.00	0.117	3
DLP SLA	1.00	1.00	3.00	1.00	2.00	0.33	0.50	2.00	1.00	0.33	0.106	4
BAT	2.00	0.33	1.00	2.00	0.33	1.00	3.00	1.00	0.30	2.00	0.091	5
LCD SLA	1.00	1.00	0.50	1.00	0.33	0.50	0.50	0.33	0.33	0.50	0.048	10
SLS	0.50	0.50	3.00	3.00	1.00	2.00	2.00	3.00	0.50	2.00	0.125	2
LOM	0.33	3.00	1.00	2.00	0.50	1.00	1.00	2.00	0.50	0.50	0.088	7
Material Jetting	0.50	2.00	0.33	2.00	0.50	1.00	1.00	0.50	0.10	0.50	0.059	9
Photopoly mer Jetting	1.00	0.50	1.00	3.00	0.33	0.50	2.00	1.00	0.50	1.00	0.076	8
FDM (pallet)	2.00	1.00	3.33	3.00	2.00	2.00	10.00	2.00	1.00	3.00	0.200	1
CLIP SLA	0.33	3.00	0.50	2.00	0.50	2.00	2.00	1.00	0.33	1.00	0.089	6

CI 0.137

Random 1.49

CR 0.092

Expert-3

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	2.00	1.00	1.00	0.50	2.00	0.095	6
DLP SLA	0.50	1.00	3.00	2.00	1.00	1.00	2.00	2.00	1.00	2.00	0.122	3
BAT	2.00	0.33	1.00	2.00	0.33	1.00	3.00	1.00	0.33	2.00	0.093	7
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.25	0.33	0.33	0.50	0.042	10
SLS	2.00	1.00	3.00	3.00	1.00	3.00	2.00	1.00	2.00	2.00	0.155	1
LOM	0.50	1.00	1.00	2.00	0.33	1.00	1.00	2.00	0.50	0.33	0.073	9
Material Jetting	1.00	0.50	0.33	4.00	0.50	1.00	1.00	0.50	2.00	0.33	0.082	8
Photopolymer Jetting	1.00	0.50	1.00	3.00	1.00	0.50	2.00	1.00	0.25	4.00	0.105	4
FDM (pallet)	2.00	1.00	3.00	3.00	0.50	2.00	0.50	4.00	1.00	0.50	0.133	2
CLIP SLA	0.50	0.50	0.50	2.00	0.50	3.00	3.00	0.25	2.00	1.00	0.099	5

CI 0.094

Random 1.49

CR 0.0629

Expert-4

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	1.00	3.00	1.00	0.50	2.00	0.096	7
DLP SLA	0.50	1.00	3.00	2.00	1.00	2.00	0.25	2.00	1.00	1.00	0.114	4
BAT	2.00	0.33	1.00	2.00	4.00	1.00	3.00	1.00	0.33	2.00	0.128	2
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.25	0.33	0.33	0.50	0.041	10
SLS	2.00	1.00	0.25	3.00	1.00	2.00	2.00	1.00	0.50	2.00	0.106	5
LOM	1.00	0.50	1.00	2.00	0.50	1.00	0.33	1.00	0.50	0.25	0.063	9
Material Jetting	0.33	4.00	0.33	4.00	0.50	3.00	1.00	1.00	0.33	0.50	0.104	6
Photopolymer Jetting	1.00	0.50	1.00	3.00	1.00	1.00	1.00	1.00	2.00	3.00	0.117	3
FDM (pallet)	2.00	1.00	3.00	3.00	2.00	2.00	3.00	0.50	1.00	2.00	0.148	1
CLIP SLA	0.50	1.00	0.50	2.00	0.50	4.00	2.00	0.33	0.50	1.00	0.084	8

*CI 0.125

Random 1.49

CR 0.0842

Expert-5

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	2.00	3.00	1.00	0.50	4.00	0.116	3
DLP SLA	0.50	1.00	2.00	2.00	4.00	1.00	0.33	2.00	1.00	0.50	0.120	2
BAT	2.00	0.50	1.00	2.00	2.00	1.00	3.00	1.00	0.33	2.00	0.112	4
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.25	0.33	0.33	1.00	0.046	10
SLS	2.00	0.25	0.50	3.00	1.00	2.00	2.00	1.00	0.50	2.00	0.105	5
LOM	0.50	1.00	1.00	2.00	0.50	1.00	1.00	2.00	0.50	0.33	0.078	9
Material Jetting	0.33	3.00	0.33	4.00	0.50	1.00	1.00	0.50	1.00	0.50	0.091	7
Photopolymer Jetting	1.00	0.50	1.00	3.00	1.00	0.50	2.00	1.00	1.00	1.00	0.093	6
FDM (pallet)	2.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00	1.00	3.00	0.151	1
CLIP SLA	0.25	2.00	0.50	1.00	0.50	3.00	2.00	1.00	0.33	1.00	0.088	8

CI 0.125

Random 1.49

CR 0.084

Expert-6

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	3.00	2.00	1.00	0.33	4.00	0.111	4
DLP SLA	0.50	1.00	3.00	2.00	1.00	0.33	1.00	2.00	1.00	0.50	0.104	6
BAT	2.00	0.33	1.00	2.00	3.00	1.00	3.00	1.00	0.33	2.00	0.120	2
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.25	0.33	0.33	1.00	0.044	10
SLS	2.00	1.00	0.33	3.00	1.00	3.00	2.00	1.00	0.50	2.00	0.114	3
LOM	0.33	3.00	1.00	2.00	0.33	1.00	0.50	2.00	0.50	1.00	0.092	7
Material Jetting	0.50	1.00	0.33	4.00	0.50	2.00	1.00	0.50	0.33	0.50	0.071	9
Photopolymer Jetting	1.00	0.50	1.00	3.00	1.00	0.50	2.00	1.00	2.00	1.00	0.106	5
FDM (pallet)	3.00	1.00	3.00	3.00	2.00	2.00	3.00	0.50	1.00	3.00	0.165	1
CLIP SLA	0.25	2.00	0.50	1.00	0.50	1.00	2.00	1.00	0.33	1.00	0.072	8

CI 0.132

Random 1.41

CR 0.089

Expert-7

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	2.00	3.00	1.00	1.00	4.00	0.124	3
DLP SLA	0.50	1.00	3.00	2.00	1.00	1.00	0.50	2.00	1.00	0.50	0.104	4
BAT	2.00	0.33	1.00	2.00	0.33	1.00	3.00	1.00	0.33	2.00	0.094	5
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.25	0.33	0.33	0.50	0.044	10
SLS	2.00	1.00	3.00	3.00	1.00	2.00	2.00	3.00	1.00	2.00	0.157	1
LOM	0.50	1.00	1.00	2.00	0.50	1.00	4.00	1.00	0.50	0.33	0.083	7
Material Jetting	0.33	2.00	0.33	4.00	0.50	0.25	1.00	0.50	0.50	0.50	0.071	9
Photopolymer Jetting	1.00	0.50	1.00	3.00	0.33	1.00	2.00	1.00	0.33	1.00	0.077	8
FDM (pallet)	1.00	1.00	3.00	3.00	1.00	2.00	2.00	3.00	1.00	3.00	0.153	2
CLIP SLA	0.25	2.00	0.50	2.00	0.50	3.00	2.00	1.00	0.33	1.00	0.092	6

CI 0.095

Random 1.49

CR 0.0637

Expert-8

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	1.50	1.50	1.00	0.50	2.50	0.095	5
DLP SLA	0.50	1.00	3.00	2.00	2.00	1.00	0.33	2.00	1.00	0.50	0.116	3
BAT	2.00	0.33	1.00	2.00	2.00	1.00	3.00	1.00	0.33	2.00	0.113	4
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.25	0.33	0.33	0.50	0.043	10
SLS	2.00	0.50	0.50	3.00	1.00	2.00	2.00	3.00	0.50	2.00	0.124	2
LOM	0.67	1.00	1.00	2.00	0.50	1.00	0.50	1.00	0.50	0.50	0.068	9
Material Jetting	0.67	3.00	0.33	4.00	0.50	2.00	1.00	0.50	0.25	0.50	0.089	6
Photopolymer Jetting	1.00	0.50	1.00	3.00	0.33	1.00	2.00	1.00	0.50	1.00	0.082	8
FDM (pallet)	2.00	1.00	3.00	3.00	2.00	2.00	4.00	2.00	1.00	3.00	0.182	1
CLIP SLA	0.40	2.00	0.50	2.00	0.50	2.00	2.00	1.00	0.33	1.00	0.087	7

CI 0.084

Random 1.49

CR 0.0566

Expert-9

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	3.00	2.00	1.00	0.50	3.00	0.108	4
DLP SLA	0.50	1.00	2.00	2.00	1.00	0.50	1.00	4.00	0.33	0.50	0.096	5
BAT	2.00	0.50	1.00	2.00	3.00	1.00	3.00	1.00	0.33	2.00	0.121	2
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.25	0.33	0.33	0.50	0.043	10
SLS	2.00	1.00	0.33	3.00	1.00	1.00	2.00	3.00	0.50	2.00	0.114	3
LOM	0.33	2.00	1.00	2.00	1.00	1.00	0.50	2.00	0.50	0.33	0.082	8
Material Jetting	0.50	1.00	0.33	4.00	0.50	2.00	1.00	0.50	0.17	0.50	0.067	9
Photopolymer Jetting	1.00	0.25	1.00	3.00	0.33	0.50	2.00	1.00	1.00	1.00	0.085	7
FDM (pallet)	2.00	3.00	3.00	3.00	2.00	2.00	6.00	1.00	1.00	3.00	0.196	1
CLIP SLA	0.33	2.00	0.50	2.00	0.50	3.00	2.00	1.00	0.33	1.00	0.088	6

CI 0.110

Random 1.49

CR 0.0736

Expert-10

Table: Pairwise comparison matrix of alternatives with respect to Dimensional Accuracy

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.50	1.00	0.50	2.00	1.00	1.00	0.50	2.00	0.096	5
DLP SLA	0.50	1.00	3.00	2.00	1.00	1.00	2.00	3.00	1.00	1.00	0.128	3
BAT	2.00	0.33	1.00	2.00	3.00	1.00	3.00	1.00	0.33	2.00	0.124	4
LCD SLA	1.00	0.50	0.50	1.00	0.33	0.50	0.33	0.25	0.50	1.00	0.050	10
SLS	2.00	1.00	0.33	3.00	1.00	3.00	2.00	2.00	1.00	2.00	0.135	2
LOM	0.50	1.00	1.00	2.00	0.33	1.00	0.50	1.00	0.50	1.00	0.071	7
Material Jetting	1.00	0.50	0.33	3.00	0.50	2.00	1.00	0.50	0.20	0.50	0.067	9
Photopolymer Jetting	1.00	0.33	1.00	4.00	0.50	1.00	2.00	1.00	0.33	1.00	0.084	6
FDM (pallet)	2.00	1.00	3.00	2.00	1.00	2.00	5.00	3.00	1.00	3.00	0.177	1
CLIP SLA	0.50	1.00	0.50	1.00	0.50	1.00	2.00	1.00	0.33	1.00	0.068	8

CI 0.052

Random 1.49

CR 0.0346

MECHANICAL PROPERTIES

Expert-1

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	3.00	3.00	3.00	4.00	0.25	0.33	0.50	2.00	0.100	4
DLP SLA	0.50	1.00	2.00	1.00	3.00	2.00	0.25	0.33	2.00	1.00	0.078	5
BAT	0.33	0.50	1.00	0.17	1.00	1.00	0.13	0.11	0.20	0.20	0.025	10
LCD SLA	0.33	1.00	6.00	1.00	3.00	4.00	0.25	0.33	0.20	1.00	0.074	6
SLS	0.33	0.33	1.00	0.33	1.00	1.00	0.25	0.11	0.20	0.33	0.028	9
LOM	0.25	0.50	1.00	0.25	1.00	1.00	0.33	0.11	0.20	0.33	0.029	8
Material Jetting	4.00	4.00	8.00	4.00	4.00	3.00	1.00	0.50	2.00	3.00	0.198	2
Photopolymer Jetting	3.00	3.00	9.00	3.00	9.00	9.00	2.00	1.00	3.00	4.00	0.263	1
FDM (pallet)	2.00	0.50	5.00	5.00	5.00	5.00	0.50	0.33	1.00	2.00	0.132	3
CLIP SLA	0.50	1.00	5.00	1.00	3.00	3.00	0.33	0.25	0.50	1.00	0.072	7

CI 0.026

Random 1.49

CR 0.0173

Expert-2

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	1.00	0.33	0.50	1.00	3.00	0.33	0.33	1.00	0.33	0.064	8
DLP SLA	1.00	1.00	0.50	3.00	0.50	1.00	0.50	0.50	2.00	1.00	0.081	7
BAT	3.03	2.00	1.00	3.00	1.00	2.00	1.00	3.00	3.00	2.00	0.169	1
LCD SLA	2.00	0.33	0.33	1.00	0.33	2.00	0.50	0.50	0.50	0.50	0.058	10
SLS	1.00	2.00	1.00	3.03	1.00	1.00	0.50	0.50	0.33	1.00	0.091	6
LOM	0.33	1.00	0.50	0.50	1.00	1.00	0.50	1.00	0.50	0.33	0.058	9
Material Jetting	3.00	2.00	1.00	2.00	2.00	2.00	1.00	1.00	4.00	0.50	0.142	2
Photopolymer Jetting	3.00	2.00	0.33	2.00	2.00	1.00	1.00	1.00	2.00	2.00	0.125	3
FDM (pallet)	1.00	0.50	0.33	2.00	3.00	2.00	0.25	0.50	1.00	3.00	0.102	5
CLIP SLA	3.00	1.00	0.50	2.00	1.00	3.00	2.00	0.50	0.33	1.00	0.111	4

CI 0.081

Random 1.49

CR 0.0546

Expert-3

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	0.50	0.33	0.50	0.20	3.00	0.50	0.50	0.33	0.33	0.050	10
DLP SLA	2.00	1.00	0.50	3.00	0.25	1.00	0.50	3.00	0.25	1.00	0.085	7
BAT	3.03	2.00	1.00	2.00	1.00	3.00	2.00	1.00	1.00	2.00	0.136	3
LCD SLA	2.00	0.33	0.50	1.00	0.33	2.00	0.33	0.50	0.33	0.50	0.054	9
SLS	5.00	4.00	1.00	3.03	1.00	2.00	2.00	3.00	1.00	2.00	0.172	1
LOM	0.33	1.00	0.33	0.50	0.50	1.00	1.00	1.00	0.50	0.50	0.056	8
Material Jetting	2.00	2.00	0.50	3.03	0.50	1.00	1.00	2.00	3.00	0.50	0.118	4
Photopolymer Jetting	2.00	0.33	1.00	2.00	0.33	1.00	0.50	1.00	2.00	3.00	0.101	5
FDM (pallet)	3.00	4.00	1.00	3.00	1.00	2.00	0.33	0.50	1.00	4.00	0.141	2
CLIP SLA	3.00	1.00	0.50	2.00	0.50	2.00	2.00	0.33	0.25	1.00	0.088	6

CI 0.097

Random 1.49

CR 0.0650

Expert-4

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.33	0.50	0.33	3.00	0.50	1.00	0.50	0.25	0.067	7
DLP SLA	0.50	1.00	0.50	3.00	0.50	1.00	0.25	0.50	0.33	0.50	0.058	9
BAT	3.03	2.00	1.00	2.00	2.00	3.00	1.00	1.00	1.00	3.00	0.150	2
LCD SLA	2.00	0.33	0.50	1.00	0.33	2.00	0.33	0.50	0.50	0.50	0.059	8
SLS	3.03	2.00	0.50	3.03	1.00	1.00	1.00	2.00	1.00	1.00	0.117	4
LOM	0.33	1.00	0.33	0.50	1.00	1.00	0.50	1.00	0.50	0.50	0.057	10
Material Jetting	2.00	4.00	1.00	3.03	1.00	2.00	1.00	3.00	5.00	2.00	0.189	1
Photopolymer Jetting	1.00	2.00	1.00	2.00	0.50	1.00	0.33	1.00	0.50	1.00	0.079	6
FDM (pallet)	2.00	3.00	1.00	2.00	1.00	2.00	0.20	2.00	1.00	3.00	0.127	3
CLIP SLA	4.00	2.00	0.33	2.00	1.00	2.00	0.50	1.00	0.33	1.00	0.097	5

CI 0.066

Random 1.49

CR 0.0442

Expert-5

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	1.00	0.33	0.50	1.00	3.00	0.33	0.33	0.50	1.00	0.068	8
DLP SLA	1.00	1.00	0.50	3.00	0.50	1.00	0.50	0.33	0.50	1.00	0.068	7
BAT	3.03	2.00	1.00	3.00	1.00	2.00	1.00	3.00	3.00	2.00	0.167	1
LCD SLA	2.00	0.33	0.33	1.00	0.33	2.00	0.50	0.50	0.33	0.50	0.058	10
SLS	1.00	2.00	1.00	3.03	1.00	1.00	0.50	0.50	1.00	2.00	0.101	4
LOM	0.33	1.00	0.50	0.50	1.00	1.00	0.50	1.00	0.50	1.00	0.064	9
Material Jetting	3.00	2.00	1.00	2.00	2.00	2.00	1.00	2.00	2.00	0.50	0.143	3
Photopolymer Jetting	3.00	3.00	0.33	2.00	2.00	1.00	0.50	1.00	4.00	4.00	0.153	2
FDM (pallet)	2.00	2.00	0.33	3.00	1.00	2.00	0.50	0.25	1.00	1.00	0.091	5
CLIP SLA	1.00	1.00	0.50	2.00	0.50	1.00	2.00	0.25	1.00	1.00	0.086	6

CI 0.063

Random 1.49

CR 0.0425

Expert-6

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	0.50	0.33	0.50	0.20	1.00	0.50	0.50	1.00	0.33	0.043	10
DLP SLA	2.00	1.00	0.50	3.00	0.25	1.00	0.50	3.00	2.00	1.00	0.100	6
BAT	3.03	2.00	1.00	2.00	1.00	3.00	2.00	1.00	3.00	2.00	0.152	2
LCD SLA	2.00	0.33	0.50	1.00	0.33	2.00	0.33	0.50	0.50	0.50	0.056	9
SLS	5.00	4.00	1.00	3.03	1.00	2.00	2.00	3.00	0.33	1.00	0.165	1
LOM	1.00	1.00	0.33	0.50	0.50	1.00	1.00	1.00	0.50	0.33	0.057	8
Material Jetting	2.00	2.00	0.50	3.03	0.50	1.00	1.00	2.00	4.00	0.50	0.118	3
Photopolymer Jetting	2.00	0.33	1.00	2.00	0.33	1.00	0.50	1.00	2.00	2.00	0.092	7
FDM (pallet)	1.00	0.50	0.33	2.00	3.00	2.00	0.25	0.50	1.00	3.00	0.112	4
CLIP SLA	3.00	1.00	0.50	2.00	1.00	3.00	2.00	0.50	0.33	1.00	0.105	5

CI 0.106

Random 1.49

CR 0.0708

Expert-7

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	1.00	0.33	0.50	0.33	3.00	0.50	1.00	0.33	0.33	0.061	8
DLP SLA	1.00	1.00	0.50	3.00	0.50	1.00	0.25	0.50	0.25	1.00	0.062	7
BAT	3.03	2.00	1.00	2.00	2.00	3.00	0.50	1.00	1.00	2.00	0.132	2
LCD SLA	2.00	0.33	0.50	1.00	0.33	2.00	0.33	0.50	0.33	0.50	0.055	10
SLS	3.00	2.00	0.50	3.03	1.00	1.00	1.00	2.00	1.00	2.00	0.124	3
LOM	0.33	1.00	0.33	0.50	1.00	1.00	0.50	1.00	0.50	0.50	0.057	9
Material Jetting	2.00	4.00	2.00	3.03	1.00	2.00	1.00	3.00	3.00	0.50	0.173	1
Photopolymer Jetting	1.00	2.00	1.00	2.00	0.50	1.00	0.33	1.00	2.00	4.00	0.114	5
FDM (pallet)	3.00	4.00	1.00	3.00	1.00	2.00	0.33	0.50	1.00	2.00	0.123	4
CLIP SLA	3.00	1.00	0.50	2.00	0.50	2.00	2.00	0.25	0.50	1.00	0.099	6

CI 0.078

Random 1.49

CR 0.0526

Expert-8

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	1.00	0.33	0.50	1.00	3.00	0.33	0.33	0.50	0.50	0.062	8
DLP SLA	1.00	1.00	0.50	3.00	0.50	1.00	0.50	0.50	0.33	0.25	0.063	7
BAT	3.03	2.00	1.00	3.00	1.00	2.00	1.00	3.00	1.00	3.00	0.158	2
LCD SLA	2.00	0.33	0.33	1.00	0.33	2.00	0.50	0.50	0.50	0.50	0.059	9
SLS	1.00	2.00	1.00	3.03	1.00	1.00	0.50	0.50	1.00	1.00	0.093	6
LOM	0.33	1.00	0.50	0.50	1.00	1.00	0.50	0.50	0.50	0.50	0.054	10
Material Jetting	3.00	2.00	1.00	2.00	2.00	2.00	1.00	1.00	5.00	2.00	0.172	1
Photopolymer Jetting	3.00	2.00	0.33	2.00	2.00	2.00	1.00	1.00	0.50	1.00	0.111	4
FDM (pallet)	2.00	3.00	1.00	2.00	1.00	2.00	0.20	2.00	1.00	3.00	0.129	3
CLIP SLA	2.00	4.00	0.33	2.00	1.00	2.00	0.50	1.00	0.33	1.00	0.098	5

CI 0.064

Random 1.49

CR 0.0433

Expert-9

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	0.50	0.33	0.50	0.20	3.00	0.50	0.50	0.50	1.00	0.057	9
DLP SLA	2.00	1.00	0.50	3.00	0.33	1.00	0.50	3.00	0.50	1.00	0.091	6
BAT	3.03	2.00	1.00	2.00	1.00	3.00	2.00	1.00	4.00	3.00	0.168	2
LCD SLA	2.00	0.33	0.50	1.00	0.25	2.00	0.33	0.50	0.33	0.50	0.055	10
SLS	5.00	3.00	1.00	4.00	1.00	2.00	2.00	3.00	1.00	2.00	0.177	1
LOM	0.33	1.00	0.33	0.50	0.50	1.00	1.00	1.00	0.50	1.00	0.060	8
Material Jetting	2.00	2.00	0.50	3.03	0.50	1.00	1.00	2.00	2.00	0.50	0.107	4
Photopolymer Jetting	2.00	0.33	1.00	2.00	0.33	1.00	0.50	1.00	3.00	4.00	0.111	3
FDM (pallet)	2.00	2.00	0.25	3.00	1.00	2.00	0.50	0.33	1.00	2.00	0.101	5
CLIP SLA	1.00	1.00	0.33	2.00	0.50	1.00	2.00	0.25	0.50	1.00	0.074	7

CI 0.080

Random 1.49

CR 0.0540

Expert-10

Table: Pairwise comparison matrix of alternatives with respect to Mechanical properties

Alternative	FDM (Filament)	DLP SLA	BAT	LCD SLA	SLS	LOM	Material Jetting	PJ	FDM (pallet)	CLIP SLA	Priorities	Rank
FDM (Filament)	1.00	2.00	0.33	0.50	0.33	3.00	0.50	1.00	0.33	0.33	0.066	7
DLP SLA	0.50	1.00	0.50	3.00	0.50	1.00	0.25	0.50	0.25	1.00	0.061	8
BAT	3.03	2.00	1.00	2.00	2.00	3.00	1.00	1.00	1.00	2.00	0.142	2
LCD SLA	2.00	0.33	0.50	1.00	0.33	2.00	0.33	0.50	0.33	0.50	0.057	10
SLS	3.03	2.00	0.50	3.03	1.00	1.00	1.00	3.00	1.00	2.00	0.135	3
LOM	0.33	1.00	0.33	0.50	1.00	1.00	0.50	1.00	0.50	0.50	0.057	9
Material Jetting	2.00	4.00	1.00	3.03	1.00	2.00	1.00	2.00	3.00	0.50	0.150	1
Photopolymer Jetting	1.00	2.00	1.00	2.00	0.33	1.00	0.50	1.00	2.00	3.00	0.111	5
FDM (pallet)	3.00	4.00	1.00	3.00	1.00	2.00	0.33	0.50	1.00	1.00	0.117	4
CLIP SLA	3.00	1.00	0.50	2.00	0.50	2.00	2.00	0.33	1.00	1.00	0.104	6

CI 0.072

Random 1.49

CR 0.0482

Expert 2: Pairwise comparison matrix for criteria with respect to objectives; CR = 9.3%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	weight	rank
Dimensional Accuracy	1	1	2	0.5	2	1	3	2	4	2	2	3	2	0.127	1
Mechanical properties	1	1	1	2	2	1	4	0.5	2	3	3	2	2	0.114	2
Manufacturing cost	0.5	1	1	4	2	3	1	1	1	2	1	3	3	0.106	3
Build volume	2	0.5	0.25	1	1	0.33	0.33	0.5	0.33	0.33	1	1	0.5	0.047	10
Post-processing	0.5	0.5	0.5	1	1	0.33	0.5	0.33	0.5	0.33	0.33	0.5	0.25	0.032	13
Raw material Availability	1	1	0.33	3	3	1	1	0.5	1	3	3	2	3	0.095	5
Technical know	0.33	0.25	1	3	2	1	1	2	2	2	2	3	2	0.094	6
Machine setup cost	0.5	2	1	2	3	2	0.5	1	3	1	3	2	2	0.106	3
Technology maintenance	0.25	0.5	1	3	2	1	0.5	0.33	1	3	2	1	2	0.073	7
Safety & Risk Level	0.5	0.33	0.5	3	3	0.33	0.5	1	0.33	1	1	1	0.33	0.052	9
Energy consumption	0.5	0.33	1	1	3	0.33	0.5	0.33	0.5	1	1	0.5	1	0.046	11
Material variety	0.33	0.5	0.33	1	2	0.5	0.33	0.5	1	1	2	1	0.5	0.046	11
Production rate	0.5	0.5	0.33	2	4	0.33	0.5	0.5	0.5	3	1	2	1	0.061	8

Expert 3: Pairwise comparison matrix for criteria with respect to objectives; CR = 9.7%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	weight	rank
Dimensional Accuracy	1	0.5	0.25	2	1	0.25	1	1	0.33	1	2	3	1	0.06	8
Mechanical properties	2	1	0.5	2	1	3	4	1	2	3	2	2	3	0.128	2
Manufacturing cost	4	2	1	2	2	3	1	1	3	2	3	1	3	0.14	1
Build volume	0.5	0.5	0.5	1	1	0.5	0.33	0.25	0.33	0.33	1	1	0.33	0.035	13
Ease of Post-processing	1	1	0.5	1	1	0.5	0.5	0.5	1	0.25	0.33	0.5	0.5	0.044	12
Raw material Availability	4	0.33	0.33	2	2	1	3	0.5	1	3	3	2	3	0.107	3
Technical know	1	0.25	1	3	2	0.33	1	1	0.5	0.5	1	3	2	0.071	6
Machine setup cost	1	1	1	4	2	2	1	1	1	2	1	3	1	0.097	4
Technology maintenance	3	0.5	0.33	3	1	1	2	1	1	2	3	1	2	0.09	5
Safety & Risk Level	1	0.33	0.5	3	4	0.33	2	0.5	0.5	1	1	0.5	0.33	0.06	8
Energy consumption	0.5	0.5	0.33	1	3	0.33	1	1	0.33	1	1	1	1	0.052	11
Material variety	0.33	0.5	1	1	2	0.5	0.33	0.33	1	2	1	1	1	0.056	10
Production rate	1	0.33	0.33	3	2	0.33	0.5	1	0.5	3	1	1	1	0.061	7

Expert 4: Pairwise comparison matrix for criteria with respect to objectives; CR = 7.8%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	weight	rank
Dimensional Accuracy	1	1	1	3	2	1	3	2	4	2	2	3	2	0.128	2
Mechanical properties	1	1	2	2	2	1	4	0.5	2	3	3	2	3	0.129	1
Manufacturing cost	1	0.5	1	4	2	3	1	1	1	2	3	4	3	0.112	3
Build volume	0.33	0.5	0.25	1	1	0.33	0.33	0.33	0.33	0.33	1	1	0.5	0.031	13
Ease of Post-processing	0.5	0.5	0.5	1	1	0.5	0.5	0.33	0.5	0.33	2	1	0.25	0.039	11
Raw material Availability	1	1	0.33	3	2	1	0.33	0.5	1	3	3	2	3	0.087	6
Technical know	0.33	0.25	1	3	2	3	1	2	2	1	2	4	2	0.103	5
Machine setup cost	0.5	2	1	3	3	2	0.5	1	3	1	3	2	2	0.106	4
Technology maintenance	0.25	0.5	1	3	2	1	0.5	0.33	1	1	2	1	2	0.063	8
Safety & Risk Level	0.5	0.33	0.5	3	3	0.33	1	1	1	1	4	1	0.5	0.066	7
Energy consumption	0.5	0.33	0.33	1	0.5	0.33	0.5	0.33	0.5	0.25	1	2	0.5	0.035	12
Material variety	0.33	0.5	0.25	1	1	0.5	0.25	0.5	1	1	0.5	1	2	0.044	10
Production rate	0.5	0.33	0.33	2	4	0.33	0.5	0.5	0.5	2	2	0.5	1	0.056	9

Expert 5: Pairwise comparison matrix for criteria with respect to objectives; CR = 9.8%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	weight	rank
Dimensional Accuracy	1	1	0.5	1	0.5	2	1	0.25	3	2	2	3	2	0.082	6
Mechanical properties	1	1	0.5	1	2	2	4	0.5	2	3	3	2	1	0.106	3
Manufacturing cost	2	2	1	3	2	4	1	0.5	2	2	1	3	3	0.123	2
Build volume	1	1	0.33	1	1	2	3	0.5	2	3	3	2	1	0.095	4
Ease of Post-processing	2	0.5	0.5	1	1	1	2	0.33	2	0.33	0.33	0.5	0.5	0.058	8
Raw material Availability	0.5	0.5	0.25	0.5	1	1	0.33	0.5	3	0.33	1	1	1	0.045	12
Technical know	1	0.25	1	0.33	0.5	3	1	1	2	2	2	3	2	0.083	5
Machine setup cost	4	2	2	2	3	2	1	1	3	1	3	2	2	0.135	1
Technology maintenance	0.33	0.5	0.5	0.5	0.5	0.33	0.5	0.33	1	0.33	2	1	0.33	0.037	13
Safety & Risk Level	0.5	0.33	0.5	0.33	3	3	0.5	1	3	1	2	2	3	0.082	6
Energy consumption	0.5	0.33	1	0.33	3	1	0.5	0.33	0.5	0.5	1	1	1	0.051	10
Material variety	0.33	0.5	0.33	0.5	2	1	0.33	0.5	1	0.5	1	1	2	0.048	11
Production rate	0.5	1	0.33	1	2	1	0.5	0.5	3	0.33	1	0.5	1	0.055	9

Expert 6: Pairwise comparison matrix for criteria with respect to objectives; CR = 9.7%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	weight	rank
Dimensional Accuracy	1	3	0.5	2	2	1	0.5	4	2	2	1	3	2	0.114	3
Mechanical properties	0.33	1	1	0.5	2	1	0.25	0.5	3	2	3	2	2	0.08	6
Manufacturing cost	2	1	1	4	2	3	1	1	1	2	1	3	3	0.118	2
Build volume	0.5	2	0.25	1	1	0.33	0.5	0.5	0.33	3	1	1	0.5	0.052	10
Ease of Post-processing	0.5	0.5	0.5	1	1	0.33	0.5	0.33	0.5	0.33	0.33	0.5	0.25	0.032	13
Raw material Availability	1	1	0.33	3	3	1	1	0.5	1	3	3	2	3	0.095	5
Technical know	2	4	1	2	2	1	1	2	2	3	2	3	2	0.129	1
Machine setup cost	0.25	2	1	2	3	2	0.5	1	3	1	3	2	2	0.102	4
Technology maintenance	0.5	0.33	1	3	2	1	0.5	0.33	1	3	1	1	2	0.07	7
Safety & Risk Level	0.5	0.5	0.5	0.33	3	0.33	0.33	1	0.33	1	0.33	2	0.33	0.043	12
Energy consumption	1	0.33	1	1	3	0.33	0.5	0.33	1	3	1	0.5	1	0.059	9
Material variety	0.33	0.5	0.33	1	2	0.5	0.33	0.5	1	0.5	2	1	0.5	0.045	11
Production rate	0.5	0.5	0.33	2	4	0.33	0.5	0.5	0.5	3	1	2	1	0.06	8

Expert 7: Pairwise comparison matrix for criteria with respect to objectives; CR = 8.9%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	Weight	Rank
Dimensional Accuracy	1	2	1	2	3	1	4	0.25	0.5	2	2	3	2	0.11	3
Mechanical properties	0.5	1	3	2	2	1	1	2	2	0.33	3	2	1	0.097	5
Manufacturing cost	1	0.33	1	3	3	0.33	0.5	1	0.33	0.5	2	2	3	0.07	8
Build volume	0.5	0.5	0.33	1	1	0.5	0.33	0.5	0.33	0.25	1	1	0.33	0.034	12
Ease of Post-processing	0.33	0.5	0.33	1	1	0.5	0.5	0.33	0.5	0.5	1	0.5	0.5	0.034	12
Raw material Availability	1	1	3	2	2	1	3	0.5	1	0.33	3	2	3	0.099	4
Technical know	0.25	1	2	3	2	0.33	1	1	0.5	1	3	2	2	0.079	7
Machine setup cost	4	0.5	1	2	3	2	1	1	3	1	3	2	2	0.126	1
Technology maintenance	2	0.5	3	3	2	1	2	0.33	1	0.5	2	1	2	0.09	6
Safety & Risk Level	0.5	3	2	4	2	3	1	1	2	1	1	3	2	0.122	2
Energy consumption	0.5	0.33	0.5	1	1	0.33	0.33	0.33	0.5	1	1	0.33	1	0.038	11
Material variety	0.33	0.5	0.5	1	2	0.5	0.5	0.5	1	0.33	3	1	2	0.052	9
Production rate	0.5	1	0.33	3	2	0.33	0.5	0.5	0.5	0.5	1	0.5	1	0.048	10

Expert 8: Pairwise comparison matrix for criteria with respect to objectives; CR = 8.4%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	weight	rank
Dimensional Accuracy	1	1	2	2	2	1	3	2	4	2	2	3	1	0.131	1
Mechanical properties	1	1	3	2	2	1	1	0.5	2	3	3	2	2	0.103	5
Manufacturing cost	0.5	0.33	1	0.25	0.5	0.33	0.33	0.25	1	1	2	1	0.33	0.038	12
Build volume	0.5	0.5	4	1	4	0.33	0.33	0.5	0.33	3	1	1	0.5	0.063	8
Ease of Post-processing	0.5	0.5	2	0.25	1	0.33	0.5	0.33	0.5	0.33	0.33	0.5	1	0.037	13
Raw material Availability	1	1	3	3	3	1	0.5	1	1	3	3	2	3	0.109	3
Technical know	0.33	1	3	3	2	2	1	3	2	2	2	3	2	0.124	2
Machine setup cost	0.5	2	4	2	3	1	0.33	1	2	1	3	4	2	0.108	4
Technology maintenance	0.25	0.5	1	3	2	1	0.5	0.5	1	2	3	1	2	0.076	6
Safety & Risk Level	0.5	0.33	1	0.33	3	0.33	0.5	1	0.5	1	2	2	0.33	0.052	9
Energy consumption	0.5	0.33	0.5	1	3	0.33	0.5	0.33	0.33	0.5	1	2	0.5	0.044	10
Material variety	0.33	0.5	1	1	2	0.5	0.33	0.25	1	0.5	0.5	1	0.5	0.041	11
Production rate	1	0.5	3	2	1	0.33	0.5	0.5	0.5	3	2	2	1	0.072	7

Expert 9: Pairwise comparison matrix for criteria with respect to objectives; CR = 8.6%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	Weight	Rank
Dimensional Accuracy	1	2	3	1	0.5	1	1	0.25	0.5	2	2	2	3	0.084	6
Mechanical properties	0.5	1	2	2	0.5	1	4	0.5	2	3	3	2	1	0.103	3
Manufacturing cost	0.33	0.5	1	1	0.33	0.5	0.5	0.33	0.5	0.33	0.33	0.5	0.33	0.031	13
Build volume	1	0.5	1	1	0.25	0.5	0.33	0.5	0.33	0.33	1	1	0.33	0.037	12
Ease of Post-processing	2	2	3	4	1	3	1	1	2	2	3	1	2	0.127	2
Raw material Availability	1	1	2	2	0.33	1	3	0.5	1	3	2	3	3	0.101	4
Technical know	1	0.25	2	3	1	0.33	1	1	0.5	2	2	3	2	0.081	7
Machine setup cost	4	2	3	2	1	2	1	1	3	1	3	2	2	0.132	1
Technology maintenance	2	0.5	2	3	0.5	1	2	0.33	1	3	2	1	2	0.089	5
Safety & Risk Level	0.5	0.33	3	3	0.5	0.33	0.5	1	0.33	1	2	0.5	3	0.063	8
Energy consumption	0.5	0.33	3	1	0.33	0.5	0.5	0.33	0.5	0.5	1	2	0.5	0.044	11
Material variety	0.5	0.5	2	1	1	0.33	0.33	0.5	1	2	0.5	1	1	0.054	10
Production rate	0.33	1	3	3	0.5	0.33	0.5	0.5	0.5	0.33	2	1	1	0.055	9

Expert 10 Pairwise comparison matrix for criteria with respect to objectives; CR = 9.4%

	Dimensional	Mechanical pro	Manu cost	Build volume	Post-processing	Raw material	Technical know	Machine setup cost	Technology maintenance	Safety	Energy consump	Material variety	Production rate	weight	rank
Dimensional Accuracy	1	0.5	1	2	0.33	1	1	0.2	0.5	2	0.5	2	3	0.064	8
Mechanical properties	2	1	2	0.5	2	1	4	0.5	2	3	3	2	1	0.11	3
Manufacturing cost	1	0.5	1	2	0.25	1	1	1	2	2	1	3	3	0.082	6
Build volume	0.5	2	0.5	1	0.5	2	1	0.5	3	3	1	2	1	0.083	5
Ease of Post-processing	3	0.5	4	2	1	0.5	2	0.33	2	3	3	2	2	0.112	2
Raw material Availability	1	1	1	0.5	2	1	3	0.5	1	3	3	2	3	0.098	4
Technical know	1	0.25	1	1	0.5	0.33	1	1	0.5	2	2	3	2	0.066	7
Machine setup cost	5	2	1	2	3	2	1	1	3	3	3	2	2	0.146	1
Technology maintenance	2	0.5	0.5	0.33	0.5	1	2	0.33	1	3	2	1	1	0.064	8
Safety & Risk Level	0.5	0.33	0.5	0.33	0.33	0.33	0.5	0.33	0.33	1	0.25	2	0.33	0.03	13
Energy consumption	2	0.33	1	1	0.33	0.33	0.5	0.33	0.5	4	1	1	2	0.056	10
Material variety	0.5	0.5	0.33	0.5	0.5	0.5	0.33	0.5	1	0.5	1	1	0.5	0.038	12
Production rate	0.33	1	0.33	1	0.5	0.33	0.5	0.5	1	3	0.5	2	1	0.051	11

PERSONAL PROFILE OF RESPONDENTS			
SL	**Name**	**Professional Experience details**	**Remarks**
01	Engr. Faruk Hannan B.Sc. in EEE (BUET) Email: 3dprintbd.farukhannan@gmail.com Mobile: 01708521991	CEO & Chairman of Icube Ltd.(3dprintbd.com). Ex. AGM of Energypac Engineering Ltd. 7+ years of experience in 3D Printing sector. Total 13 years professional experience	Respond
02	Hannes Kirchhoff German Entrepreneur Email: hannes.kirchhoff@me-solshare.com (BD) +880 17 03 97 98 04 (DE+WA) +49 (171) 155 21 41 Skype: hannes.c.kirchhoff	CTO, SOLshare Bangladesh German Company Liaison office in BD SOLshare - Global Technology Pioneer of 2018: World Economic Forum Total 16 years professional experience	Respond
03	Prof. Dr. A M M Mukaddes B.Sc. in ME Email: mukaddes1975@gmail.com Mobile: 01777891684	Professor Department of Industrial and Production Engg. Shahjalal University of Science and Technology, Sylhet-Bangladesh 4+ years of experience in 3D Printing sector. Total 19 years professional experience	Partially Respond
04	Engr. Md. Munirul Alam B.Sc. in EEE (BUET) Email: munir.inovace@gmail.com Mobile: 01911109137	CEO, Inovace Technologies Inc. Dhaka- Bangladesh. 3+ years of experience in 3D Printing sector. Total 7 years professional experience	Respond
05	Engr. Md. Masud Rana B.Sc. in ME(CUET) Email: masudbitac.gov@gmail.com Mobile: 01718862601	Executive Engineer, BITAC Bangladesh Industrial Technical Assistance Centre, BITAC 4+ years of experience in 3D Printing sector. Total 19 years professional experience	Respond
06	Engr. Aowal Hossain B.Sc. in ME (CUET) Email: aowal09cuet@gmail.com Mobile: 01678860396	Deputy Director, (R&D)Walton 5+ years of experience in 3D Printing sector. Total 7 years professional experience	Respond

07.	Engr. Abdullah Al Maruf B.Sc. in IPE(SUST) Email: marufenergy@gmail.com Mobile: 01717787320	Director, Idea 3D Solutions 3D printing company 6+ years of experience in 3D Printing sector. Total 9 years professional experience	Respond
08	Prof. Dr. Tawhid Kawsar B.Sc. EEE(BUET), M.S(USA) Email: mkawser@hotmail.com Mobile: 01742205081	Professor Department of EEE Islamic University of Technology(IUT) 7+ years of experience in 3D Printing sector. Total 19 years professional experience	Respond
09	Engr. Ariful Islam Tusher *B.Sc. in EEE(DU)* *Email:* *aitusher1991@gmail.com* Phone: 01521515462	Lecturer & Fablab Manager(DU) Department of Electrical and Electronic Engineering University of Dhaka. 3+ years of experience in 3D Printing sector. Total 7 years professional experience	Partially respond
10	Engr. Kamal Mohammad B.sc. in IPE, M.Sc. in Additive Manufacturing (Germany) Email: kamal_13m@yahoo.com	Engineer (R&D), DMG MORI (Germany) 7+ years of experience in 3D Printing sector. Total 13 years professional experience	Respond
11	Nazmul Hoque Bachelor in Fine arts(DU) Email: liveaxis3d@gmail.com Mobile:	CEO, Live Axis 3D Architect (Maverick 6+ years of experience in 3D Printing sector. Total 11 years professional experience	Respond
12	Engr. Munmun Khan B.Sc. in EEE(BUET) Email: +880-1706621599 munmun25219@yahoo.com	Director Ison 3D 6+ years of experience in 3D Printing sector. Total 18 years professional experience	Partially respond
13.	Engr. Moin Uddin Quader B.Sc. in EEE(CUET) Email: moinuddinquader@gmail.com Phone: 01673013340	Manager (BSRM) Ex. FabLab Guru (CUET) 3+ years of experience in 3D Printing sector. Total 7 years professional experience	Respond

SURVEY QUESTIONNAIRE

(The objective of this survey is to collect data for M.Sc. thesis purpose under Bangladesh university of engineering & Technology (BUET). The research area is the 3D Printing Technology in Bangladesh. Collected data will be used only for academic purpose.

Name:

Designation & Organization Name:

Educational Qualification:

Related Professional experience:

Email: Phone:

Guide lines for filling and establishing relative importance:

Each criterion will be rated according to its degree of relative importance to another criterion within the group in the bases of pair wise comparison. The consistency of replies will be tested. The results will be sent to the respondent to think about his replies where no consistency achieved. Participants who did not achieve acceptable level of consistency will be requested to refill the questionnaire until they reach an acceptable level of consistency.

The scale used to find pair wise relative importance is nine-point scales as follows: **You can add any scale between 1 and 9**

(1) Equally important/preferred
(3) Moderately important/preferred
(5) Strongly important/preferred
(7) Very strongly important / preferred
(9) Extremely important/preferred.

Criteria	Quality	Price	Service
Quality	1	1/2	3
Price	2	1	7
Service	1/3	1/7	1

Any criteria can take a degree between 1 to 9 if they are equally or more important. However, if the criteria are less important it can take the inverse of the scale. In the above table you find that when the criteria have an equal importance it takes score (1). This usually happened when you compare the criteria with itself. When one criterion is from equally to moderately important it takes the score (2) and so on you can continue to evaluate to how much each criterion is preferred than the other. In the table, quality is moderately important than service while the price is very strongly important than service. This means that when service compared with price then the service is preferred by 1/7 of price.

Pairwise comparison matrix for criteria: Select the degree of relative importance/preference of each main criterion compared to each other according to the following scale :(1) Equally important /preferred (3) Moderately important /preferred (5) Strongly important /preferred (7) Very strongly important /preferred (9) Extremely important/preferred. You can add any scale between 1 and 9

Criteria	Dimensional Accuracy	Mechanical properties	Manufacturing cost	Build volume	Post-processing/ Support	Raw material availability	Machine setup cost	Technology maintenance	Safety & Risk Level	Energy consumption &Utilization	Material variety	Production rate	Technical Know How
Dimensional Accuracy													
Mechanical properties													
Manufacturing cost													
Build volume													
Post-processing/support													
Raw material Availability													
Machine setup cost													
Technology maintenance													
Safety & Risk Level													
Energy consumption & Utilization													
Material variety													
Production rate													
Technical Know How													

Relative preference of alternatives for 3D Printing Technology selection considering small batch production of polymer products in SME industries)

Brief description of available 3D printing technologies for polymer based product manufacturing

Serial	Technology Name	Description	Brand Name
01	FDM (Filament based)	Fused deposition modeling; also called FFF(Fused filament fabrication)	Prusa, Reprap, Karika, Zortrax, Ultimaker etc.
02	DLP SLA	Digital Light Processing Stereolithography	Flashforge Hunter, Kudo3D Titan 2 HR
03	BINDER Adhesive TYPE	It is also called Binder Jetting	ProJet MJP 5600
04	LCD SLA	Liquid Cristal Display Stereolithography; Also called Laser based SLA	Zortrax Inkspire, Prusa SL1
05	SLS	Selective Laser Sintering	DynamicalTools ST30, FormlabFuse1, SharebotSnowwhite
06	LOM	Laminated Object Manufacturing	Solido3d, EnvisionTEC, Mcor
07	Material Jetting	Also called DoD (Drop on Demand)	ProJet, AMpolar i2
08	Photopolymer Jetting (PJ)	Photopolymer Jetting	Polyjet, HP Multi Jet Fusion
09	FDM (pallet based)	Fused deposition modeling; Material comes directly from pallet	Titan Robotics
10	CLIP SLA	Continuous Liquid Interface Production Stereolithography	Carbon3D

Select the degree of relative preference of each alternative with respect to each criterion [between 1 to 9 scale]

1. *Dimensional Accuracy*	FDM (Filament based)	DLP SLA	BINDER Adhesive TYPE	LCD SLA	SLS	LOM	Material Jetting	Photopolymer Jetting	FDM (pallet based)	CLIP SLA
FDM (Filament based)	1.00									
DLP SLA		1.00								
BINDER Adhesive TYPE			1.00							
LCD SLA				1.00						
SLS					1.00					
LOM						1.00				
Material Jetting							1.00			
Photopolymer Jetting (PJ)								1.00		
FDM (pallet based)									1.00	
CLIP SLA										1.00

Select the degree of relative preference of each alternative with respect to each criterion [between 1 to 9 scale]

2. ***Mechanical Properties***	FDM (Filament based)	DLP SLA	BINDER Adhesive TYPE	LCD SLA	SLS	LOM	Material Jetting	Photopolymer Jetting	FDM (pallet based)	CLIP SLA
FDM (Filament based)	1.00									
DLP SLA		1.00								
BINDER Adhesive TYPE			1.00							
LCD SLA				1.00						
SLS					1.00					
LOM						1.00				
Material Jetting							1.00			
Photopolymer Jetting (PJ)								1.00		
FDM (pallet based)									1.00	
CLIP SLA										1.00

- Give your suggestion for Technology Transfer of 3D printing Technology in Bangladesh:

- How to use and integrate the strength of Educational Institutes, Government & Industry in the 3D Printing technology transfer process in Bangladesh?

- What's the major role of Educational Institutes in 3D Printing technology transfer process in Bangladesh?

- What's the major role of Government in 3D Printing technology transfer process in Bangladesh?

- What's the major role of 3D Printing Industry in 3D printing technology transfer process in Bangladesh?